Mandate

-BriX workshop "Nuclear Physics Research at the MYRRHA Accelerator".
-http://www.sckcen.be/sckcen_en/activities/conf/conferences/brix/index.shtml

- Overview of the present and future activities for the production of high intensity radioactive ion beams at ISOLDE-CERN (including a very brief overview of ISOLDE's research program, to set the scene).
- Advice on the feasibility, interest and need for intense radioactive ion beams of alkali and gaseous elements available for long beam times.
- Impression about the idea of our plans for nuclear physics research at the MYRRHA accelerator.

Concerning your specific question on the proton beam characteristics, a linear accelerator is the scenario that is chosen. More information is available on the MYRRHA website:
http://www.sckcen.be/myrrha/home.php

Mark told me about your suggestion for medical applications related to RIB's as well as about Yacine Kadi who could contribute as well.

From ISOLDE to MYRRHA

Isotope Separation On-Line
Radioisotope Ion-Beams production
Physics with RIBs at ISOLDE

- Nuclear reactions, cross sections
- Isotope production rates
- Release and decay losses
- Ionization efficiencies
- Selectivity
- RIB-Yields
- Heat dissipation (EURISOL-DS)

- Nuclear & Atomic Physics
- Astrophysics
- Solid state physics
- Post accelerated RIBs
- RIBs for medical applications and research

Feasibility

Interest
& Need

Multi-purpose
hYbrid Research Reactor
for
High-tech *RIBs* Applications ?

Historic snapshot of ISOLDE's RIB production

1951 University of Copenhagen: *Birth of RIBs*
Xe radioisotopes produced via neutron induced fission of uranium

- 1961 First experiment by Danish Radio-Alchemists at the SC.
- 1967 *ISOLDE at the SC*; 10 nA, 600 MeV p^+
- 1974 ISOLDE 2, 1 μA
- 1982 High Resolution mass Separator *1965-1990: 334 targets*

- 1992 *ISOLDE at the PSB*; 2 μA, 1 GeV p^+
- 1999 4 μA, 1.4 GeV p^+
- 2000 REX ISOLDE
- 2002 Push-pull operations (2 Front-Ends)
- 2006 LARIS laboratory
- 2007 RFQ-Cooler & Buncher
- *2008 Solid state RILIS* *1992-2007: 370 targets*

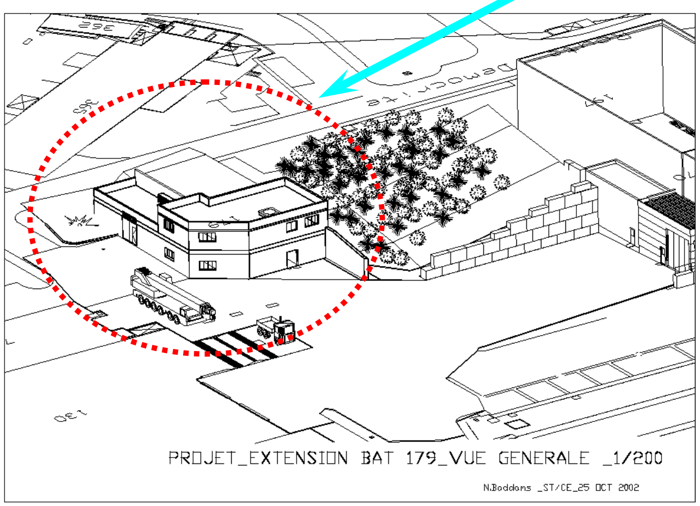
377 Physics 8h-shifts/year
~23 Target and ion-source units/year

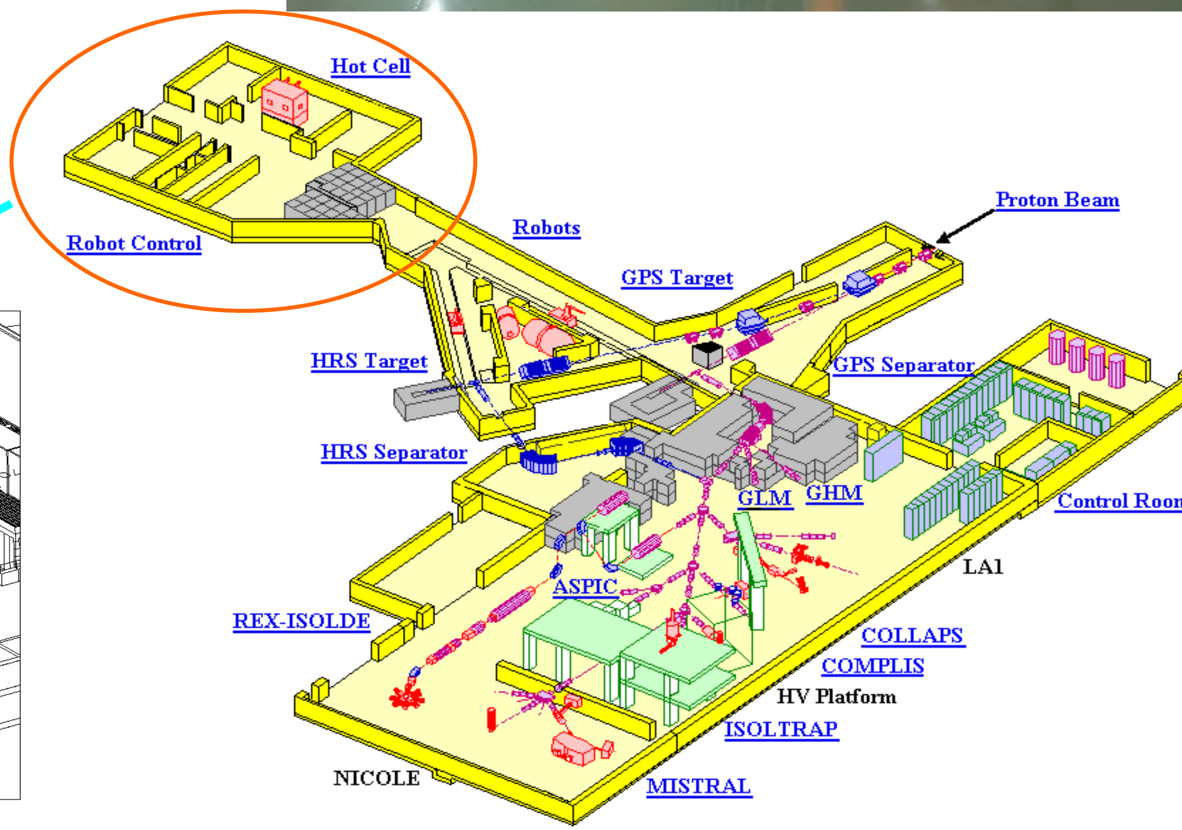
One thousand Radioisotope Ion beams from seventy elements

ISOLDE Target station & target handling robots

Class A laboratory

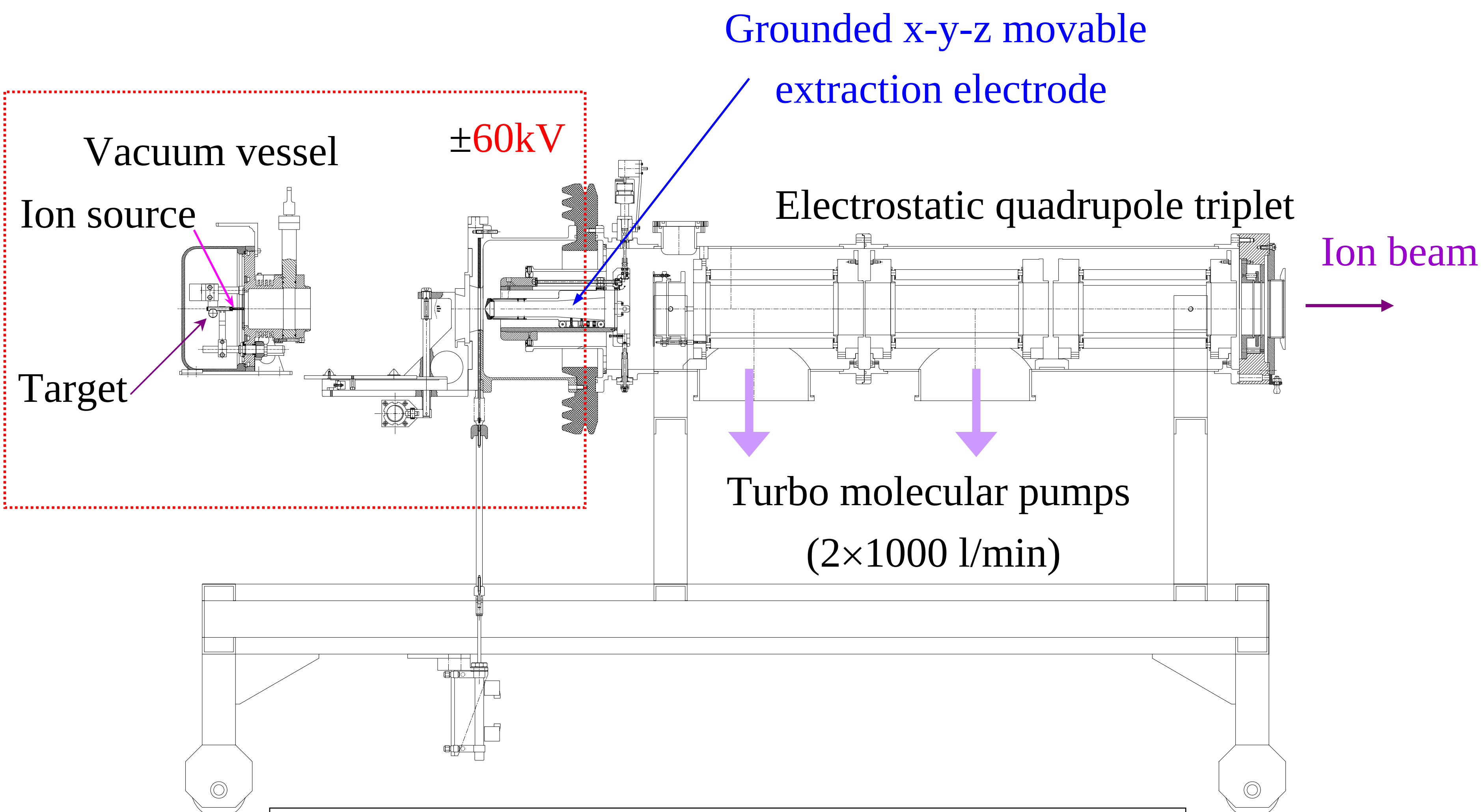
$\Sigma_{Isotopes}$ *(Activity/LA)* > 10’000





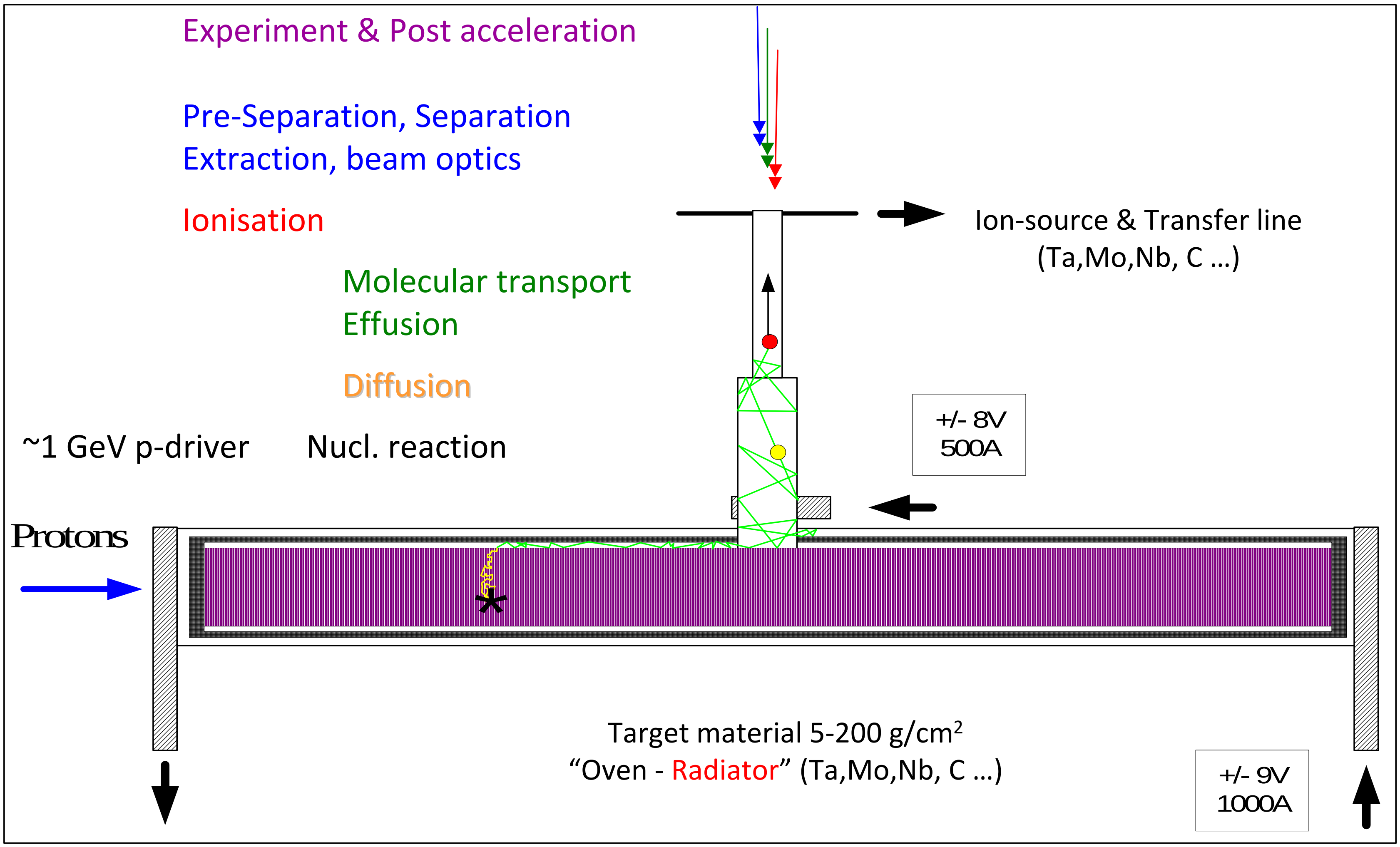
ISOLDE 60 kV Electrostatic accelerator

Av. P-beam intensities:
ISOLDE: 2 μA - O(30 mSv/h) Hands on maintenance
MYRRHA: 200 μA - O(3 Sv/h) *full remote handling*

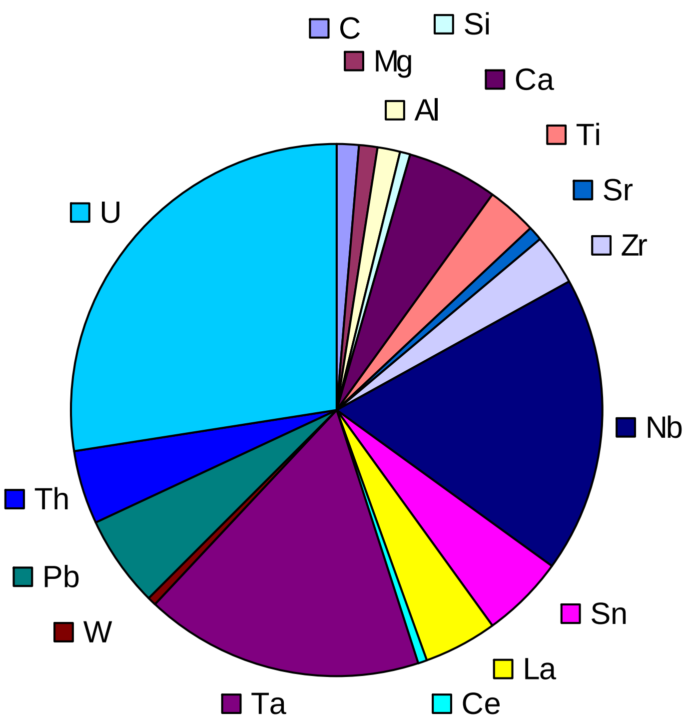


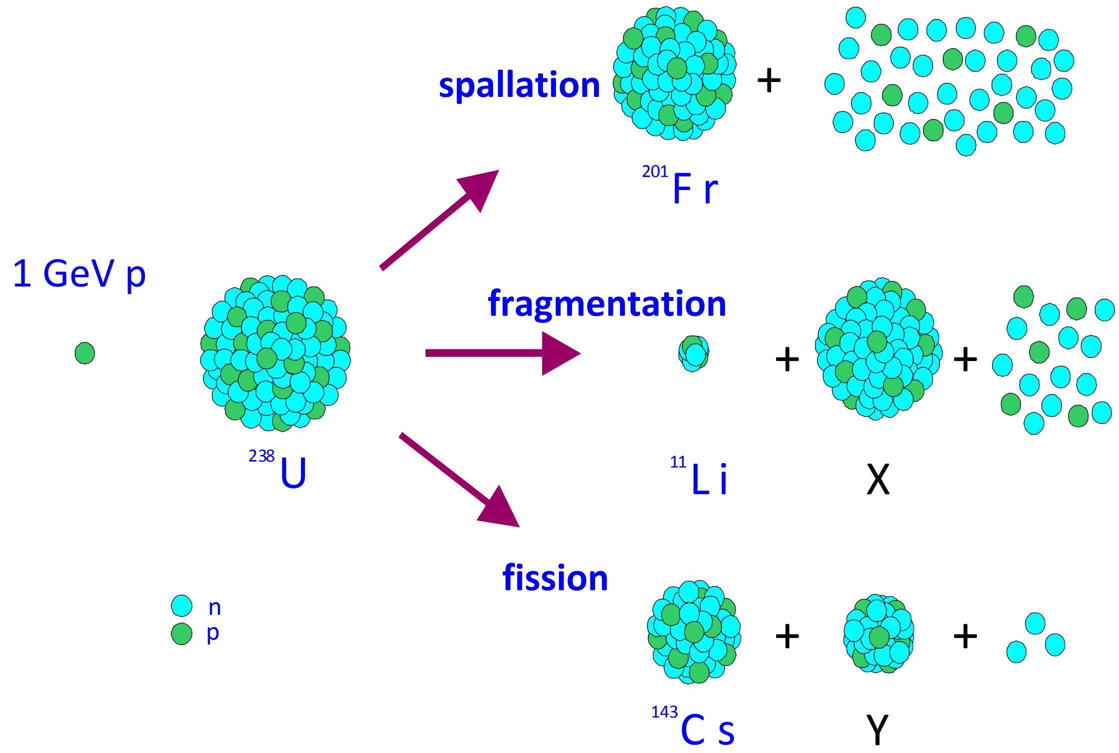
Protons: 5×10^{19} p/y, Material Dose: 5 MGy/y
Contamination (after 6 month cooling): > MBq/cm2

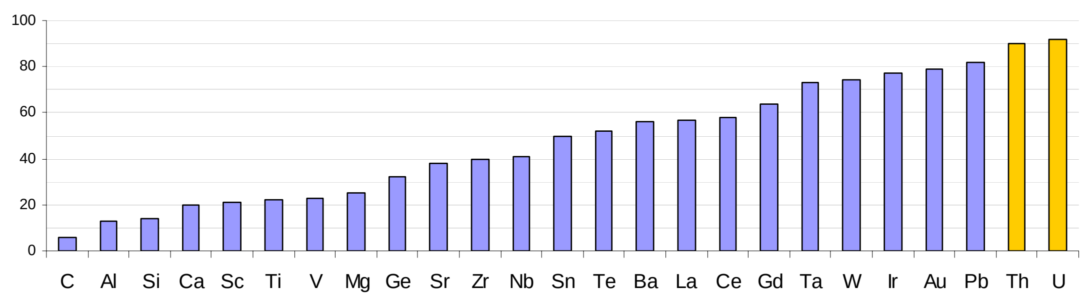
“Thick” target ISOL



Target materials & nuclear reactions

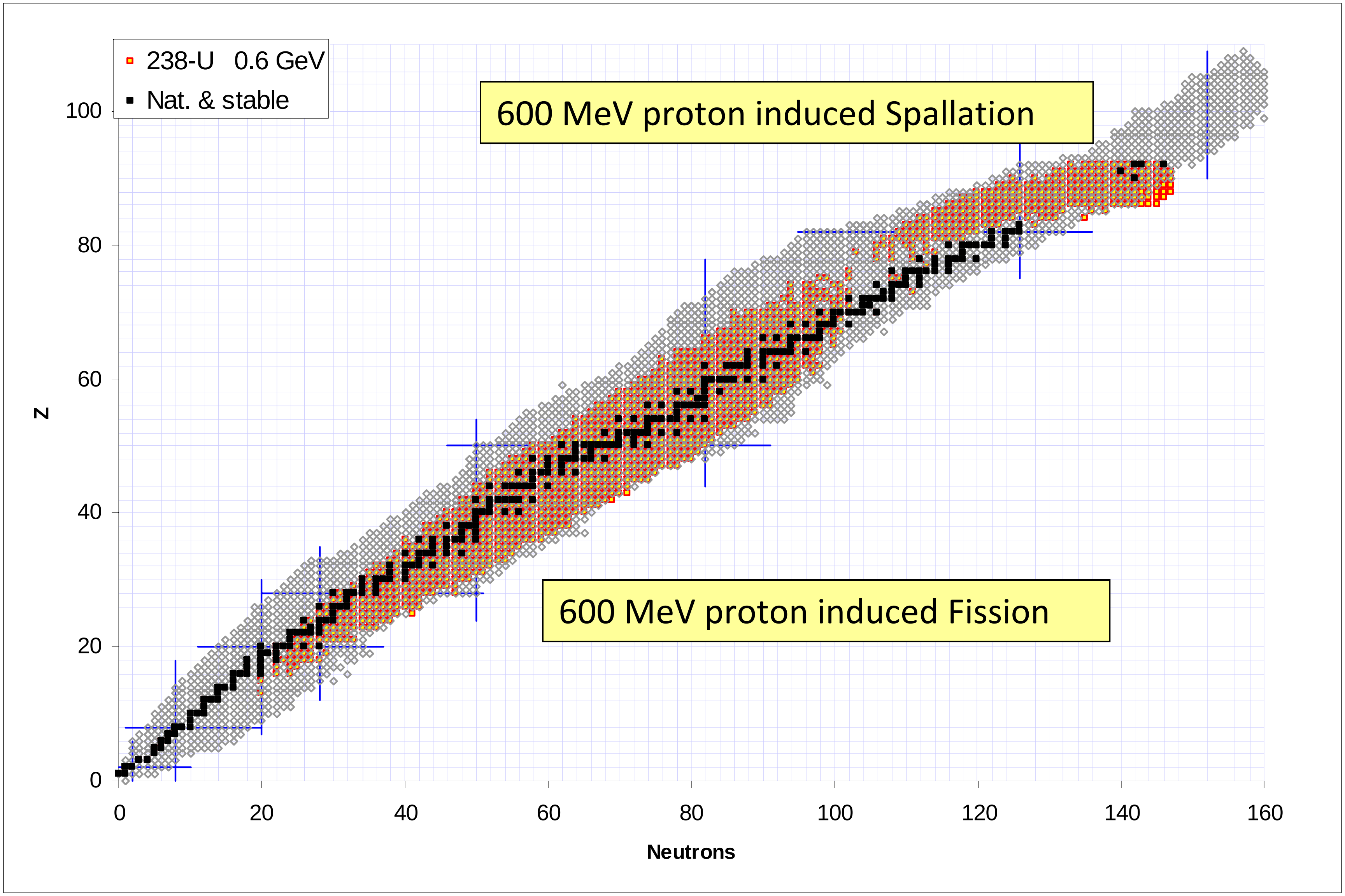






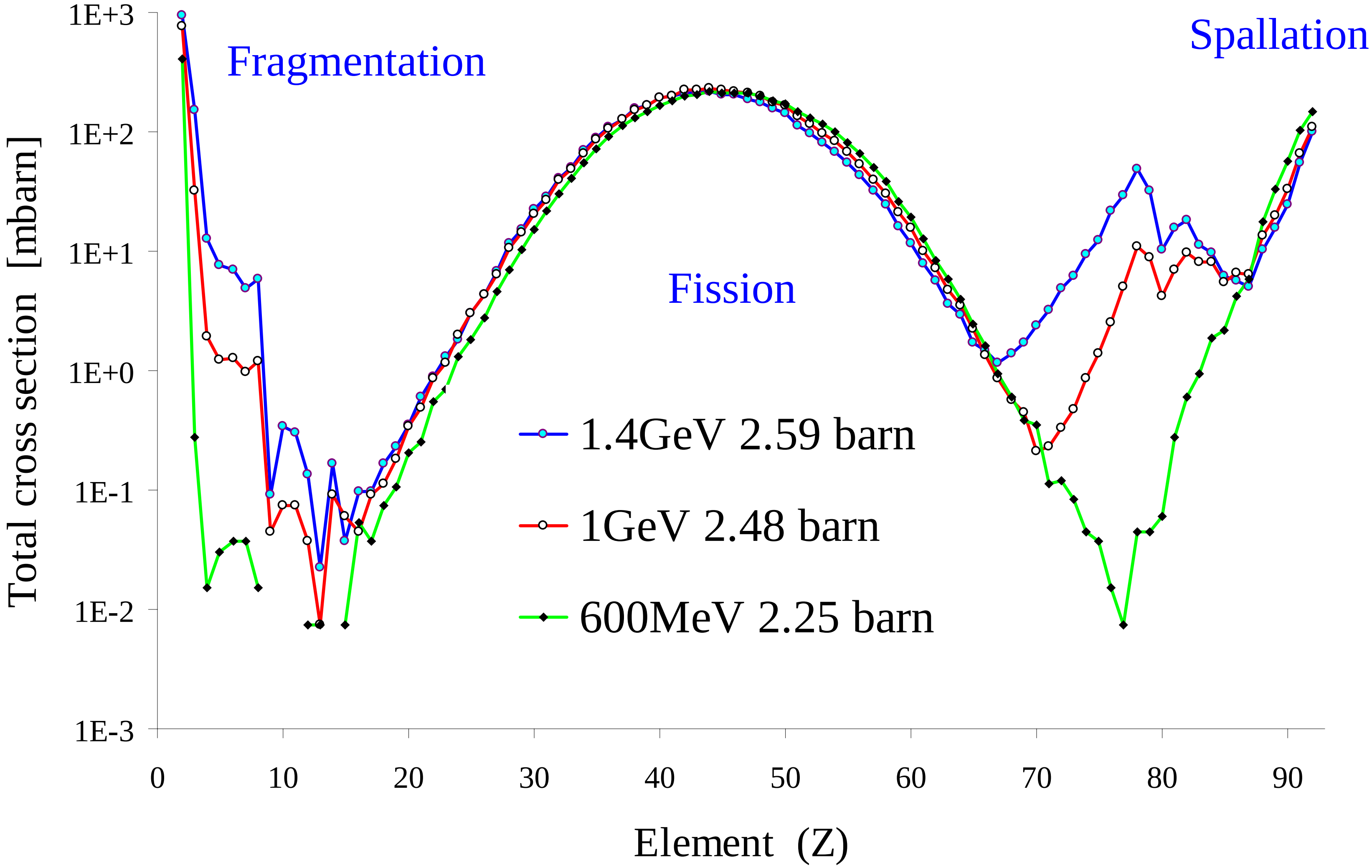
Spallation, Fragmentation & fission

U + 600 MeV p CASCABLA, A. Junghans



High energy protons on ^{238}U

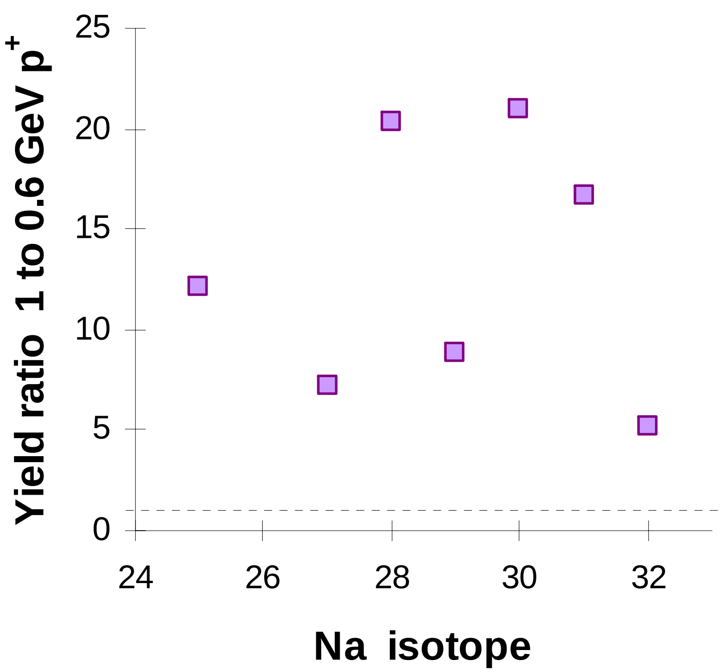
Production cross sections CASCABLA (AD 2000), A. Junghans



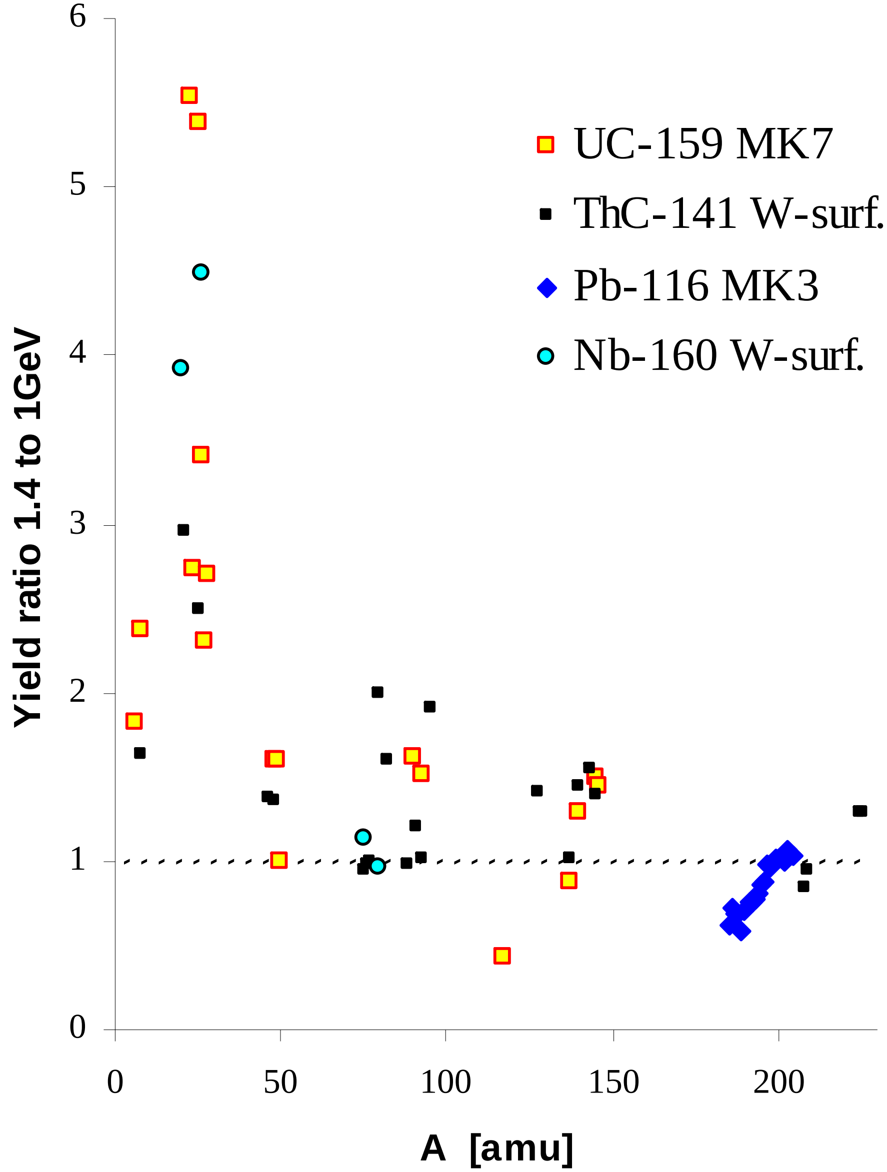
- The production cross sections are summed for all isotopes of an element
- The total cross section are given for 0.6, 1 and 1.4 GeV protons.

Yields obtained with 0.6, 1.0 & 1.4 GeV protons

SC to PS-Booster:
600 MeV to 1.0 GeV p^+



PS-Booster: 1 GeV to 1.4 GeV p^+

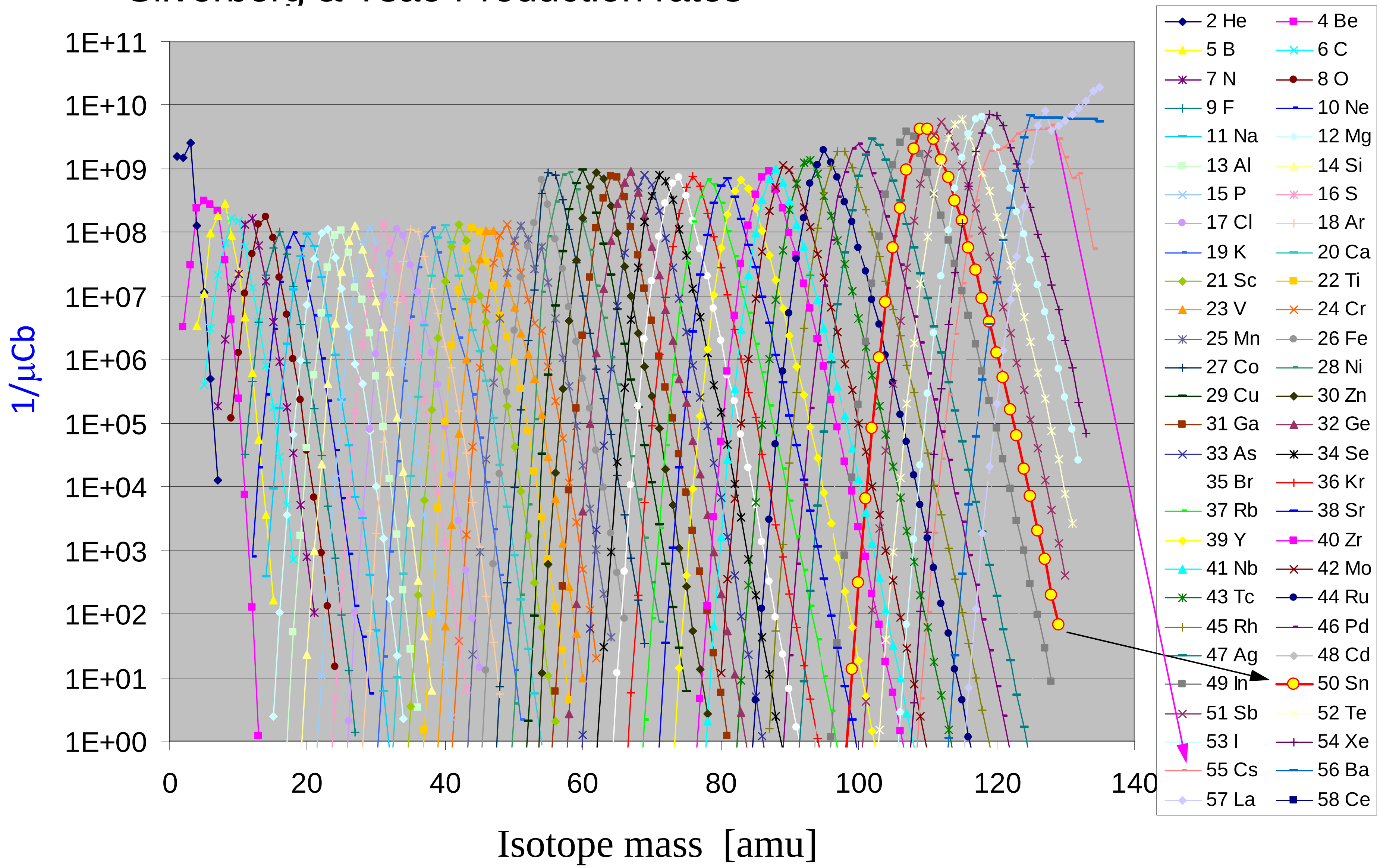


Beam purification:

1 GeV p + LaC target 10 g/cm^2

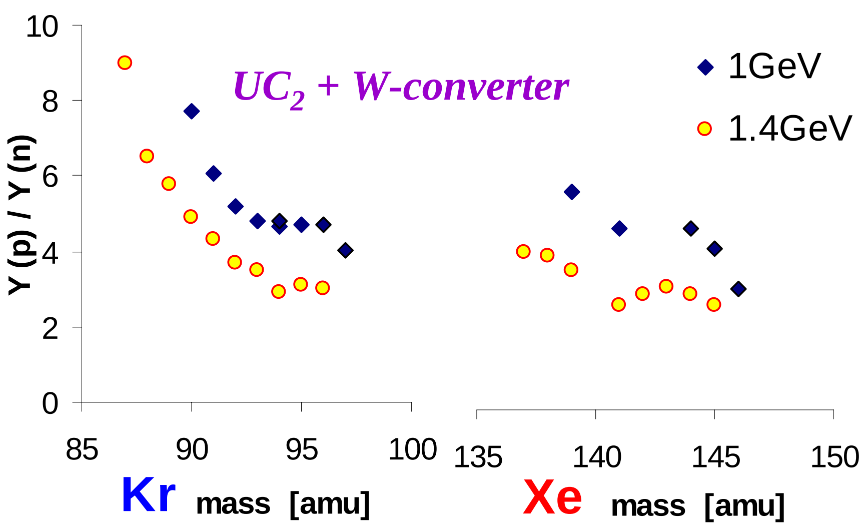
Silverberg & Tsao Production rates

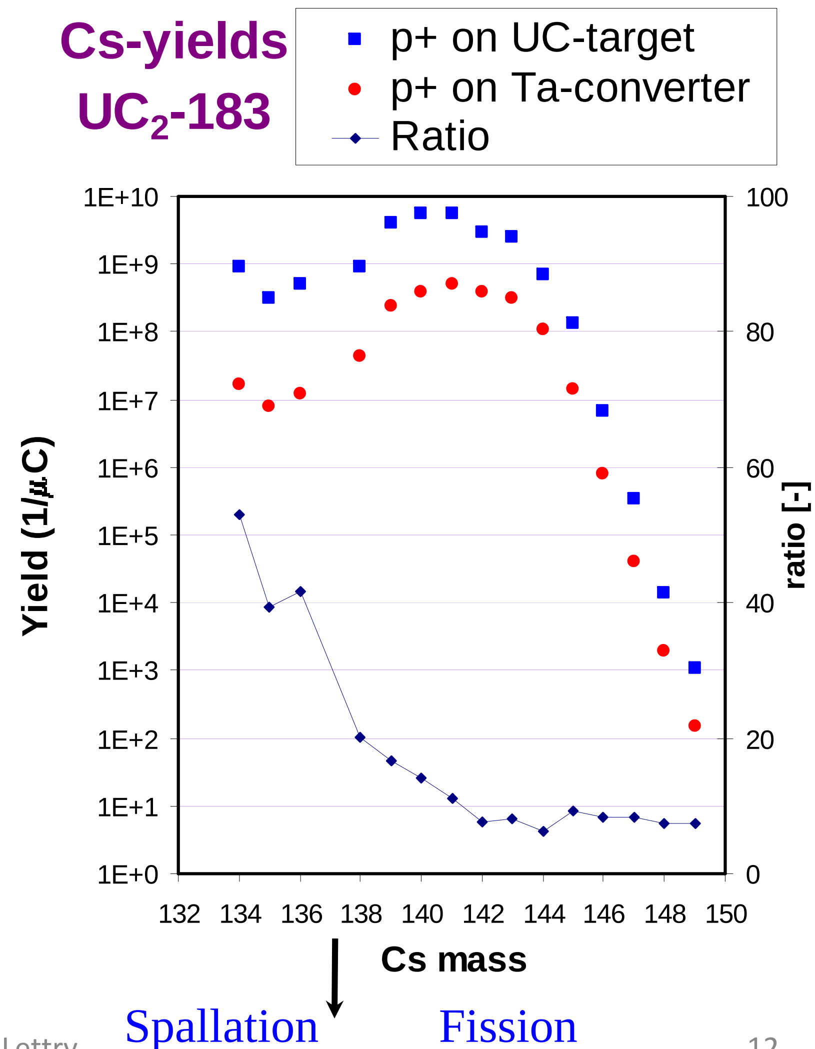
Not very convenient !



Neutrons vs. 1-1.4 GeV protons
Yields of Kr, Xe and Cs for a 50 g/cm2 depleted U-target

The yields of very n-rich isotopes obtained via neutron induced fission of Th or U are close to those of high energy protons.

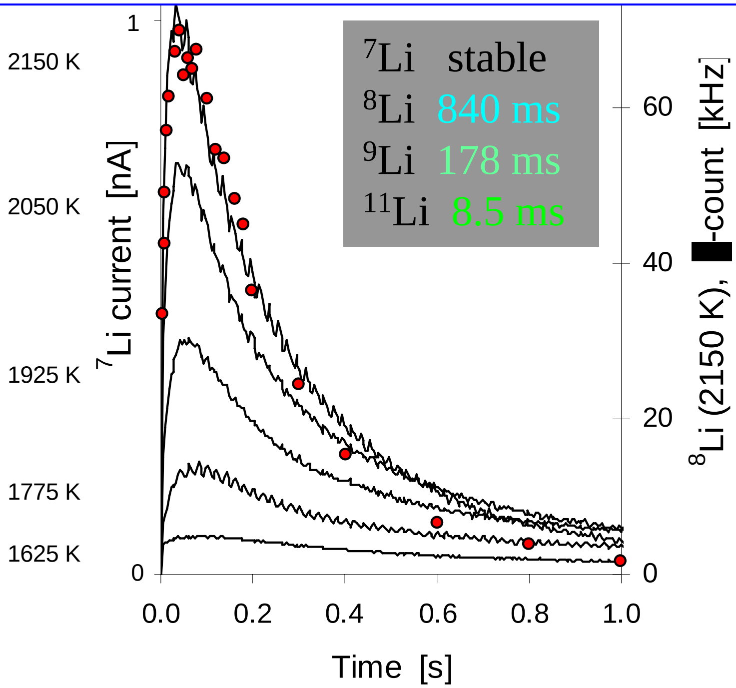


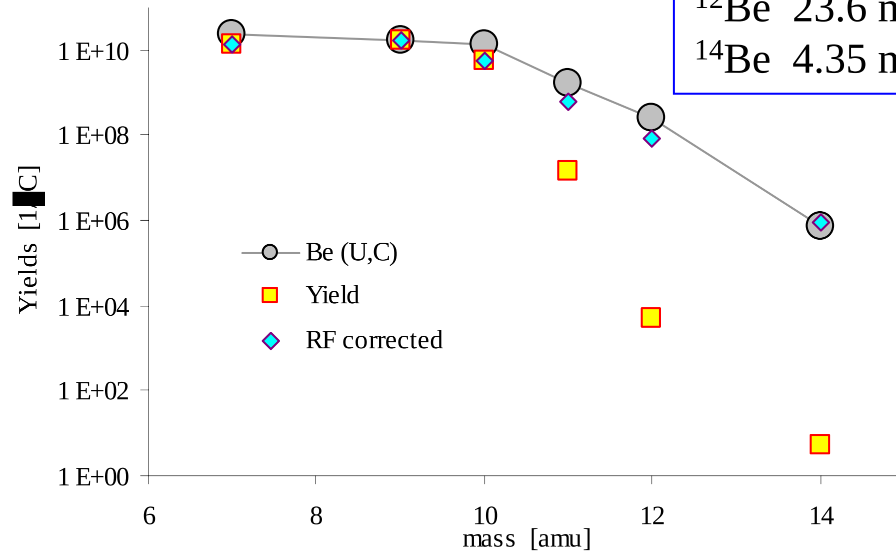


Lithium-Release

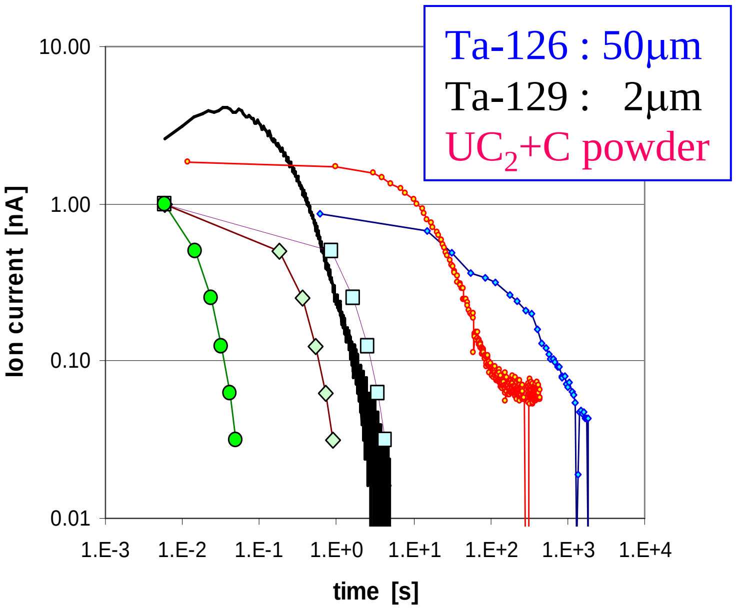
Beryllium decay losses

^{7}Be	53.3 d
^{9}Be	stable
^{10}Be	1.6 My
^{11}Be	13.8 s
^{12}Be	23.6 ms
^{14}Be	4.35 ms





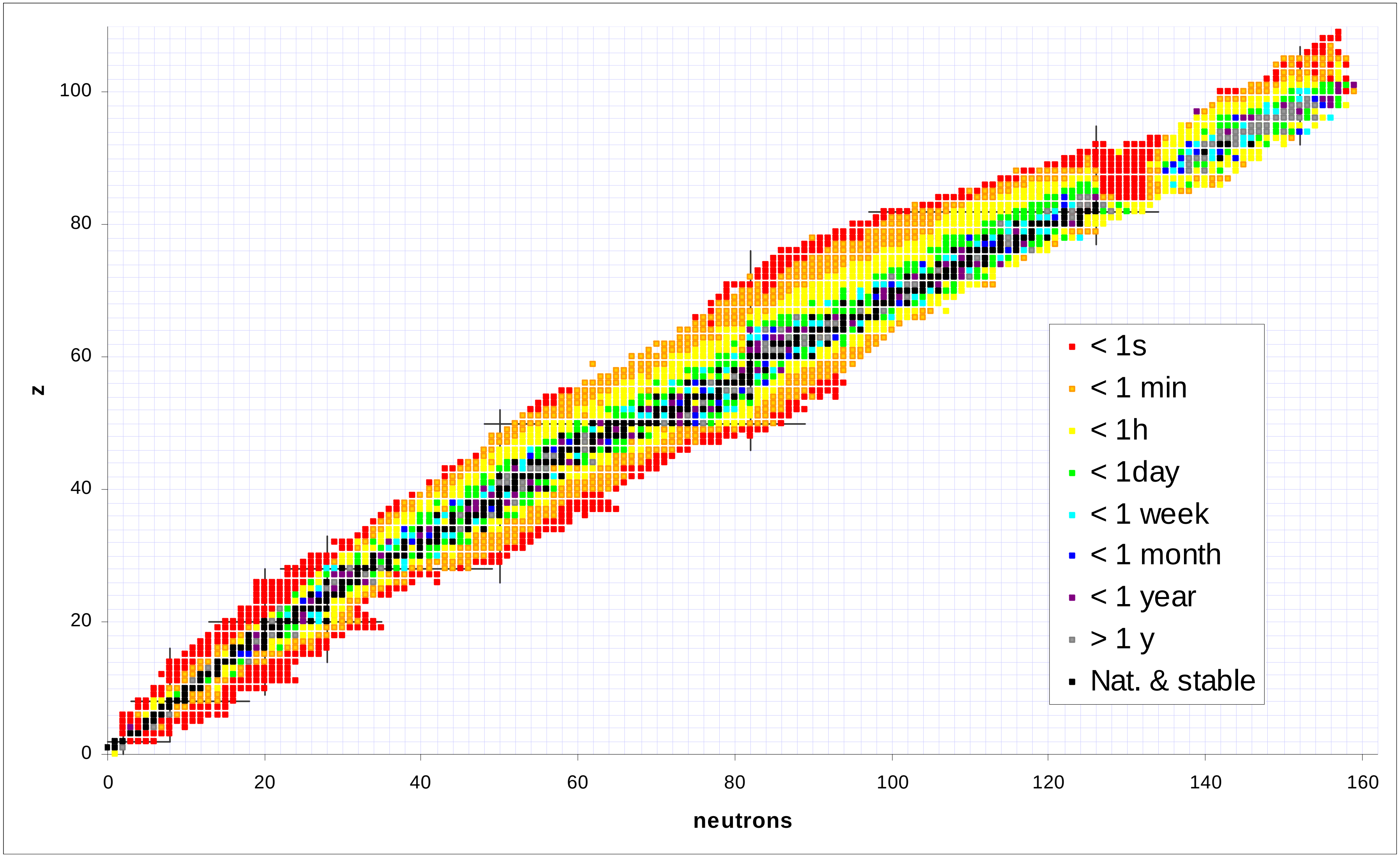
Decay losses of 4 orders of magnitude for very short lived isotopes



Diffusion & Effusion

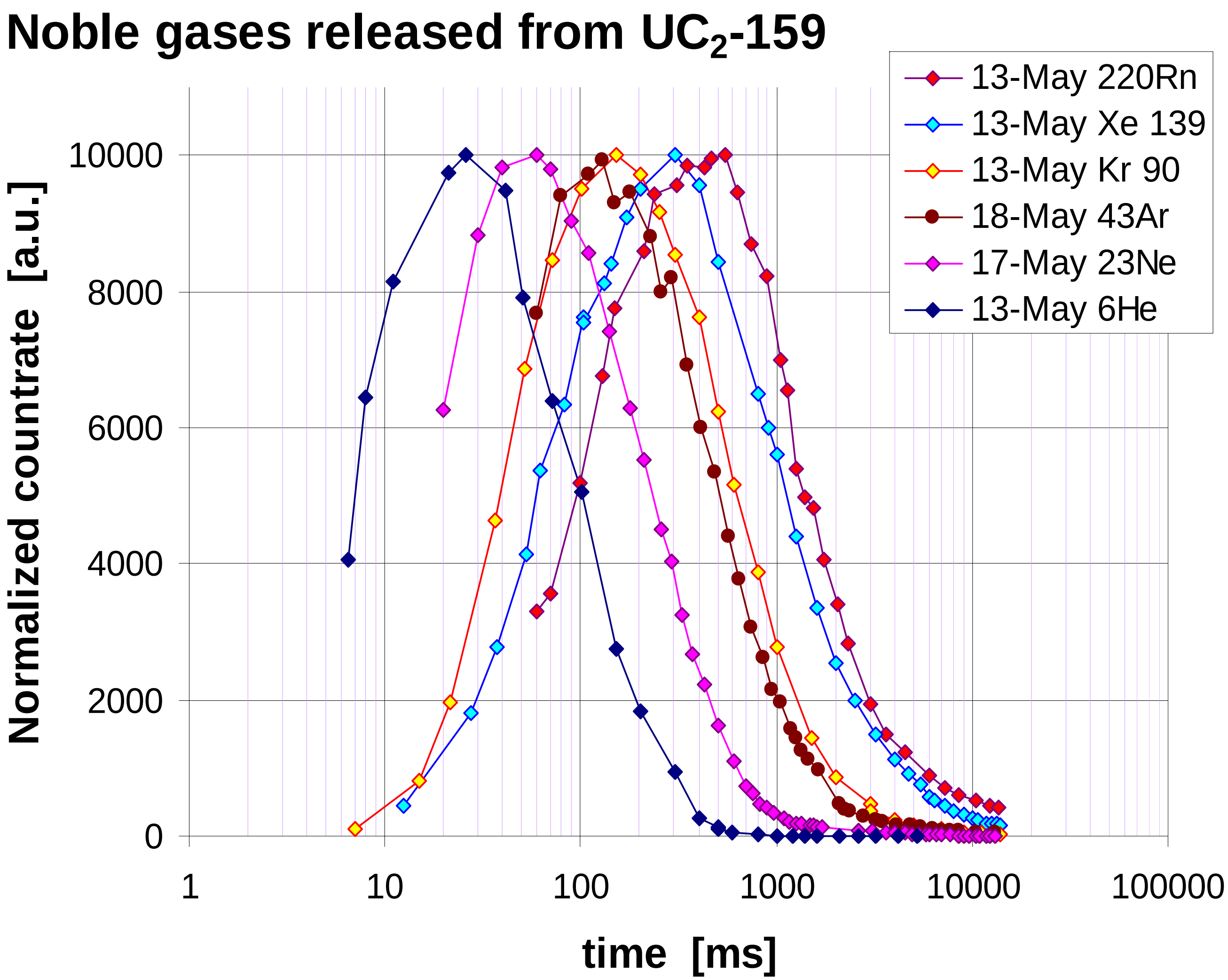
High temperature and minimum foil thickness, fiber diameter or grain size

Half lives



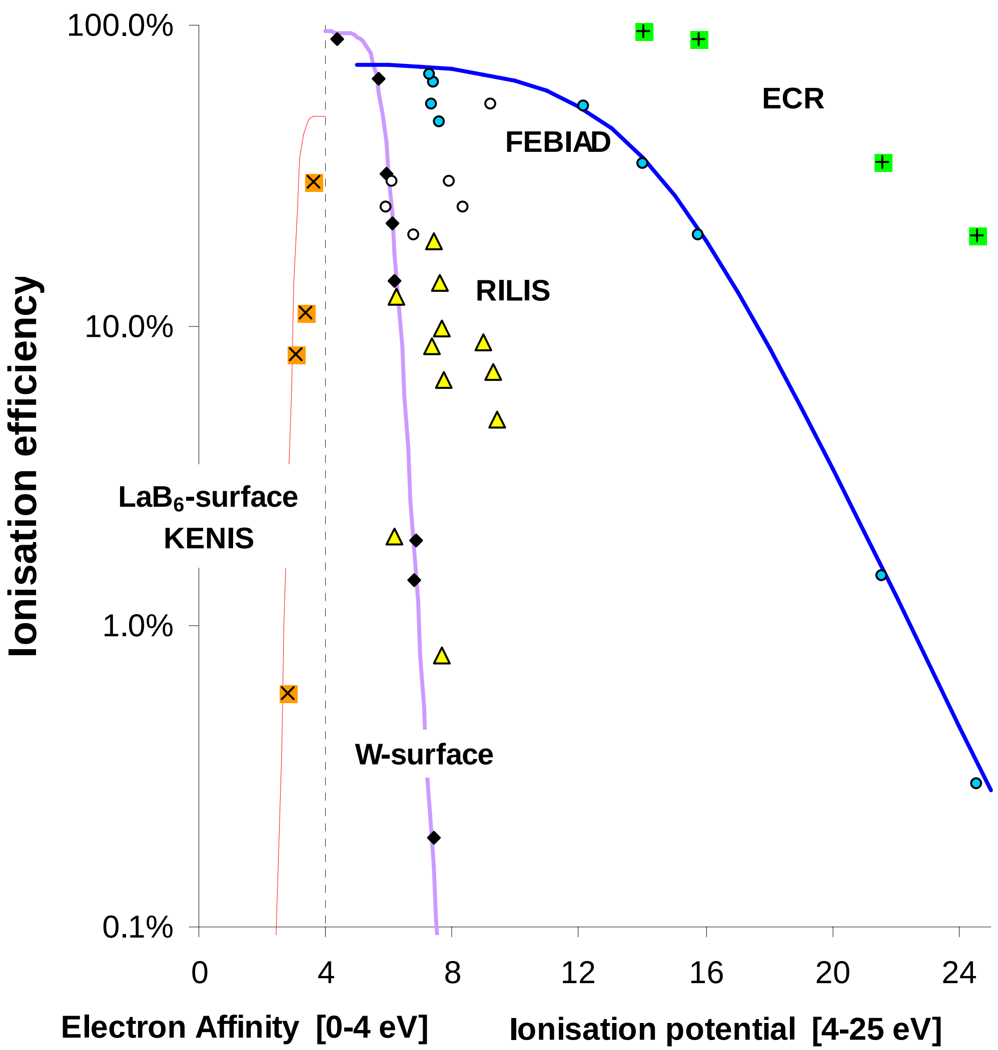
100
80
60
40
20
0
z
0
20
40
60
80
100
120
140
160
neutrons
< 1s
< 1 min
< 1h
< 1day
< 1 week
< 1 month
< 1 year
> 1 y
Nat. & stable

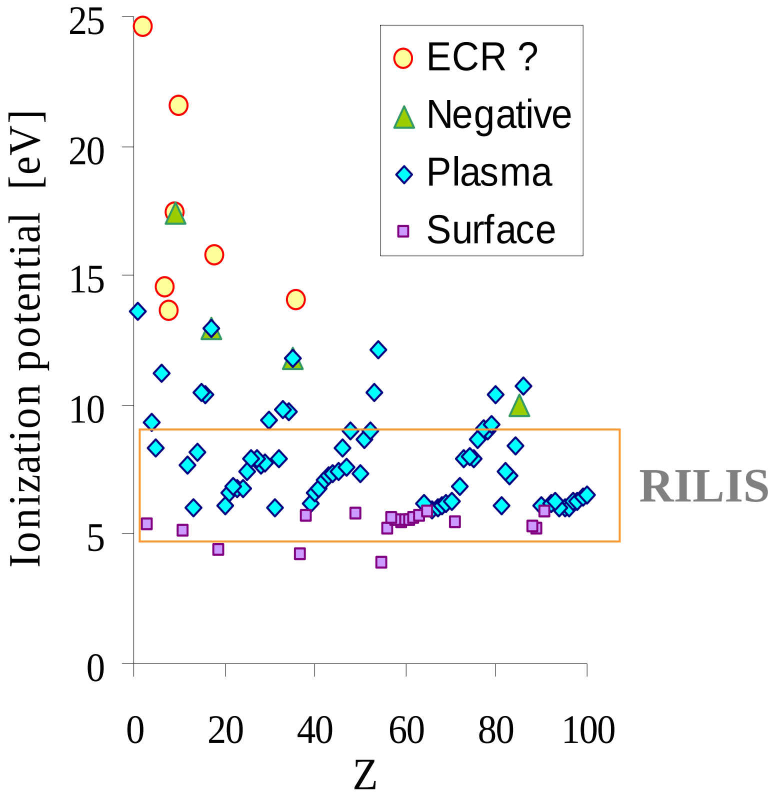
Noble gases from UCx target and MK7 ion-source



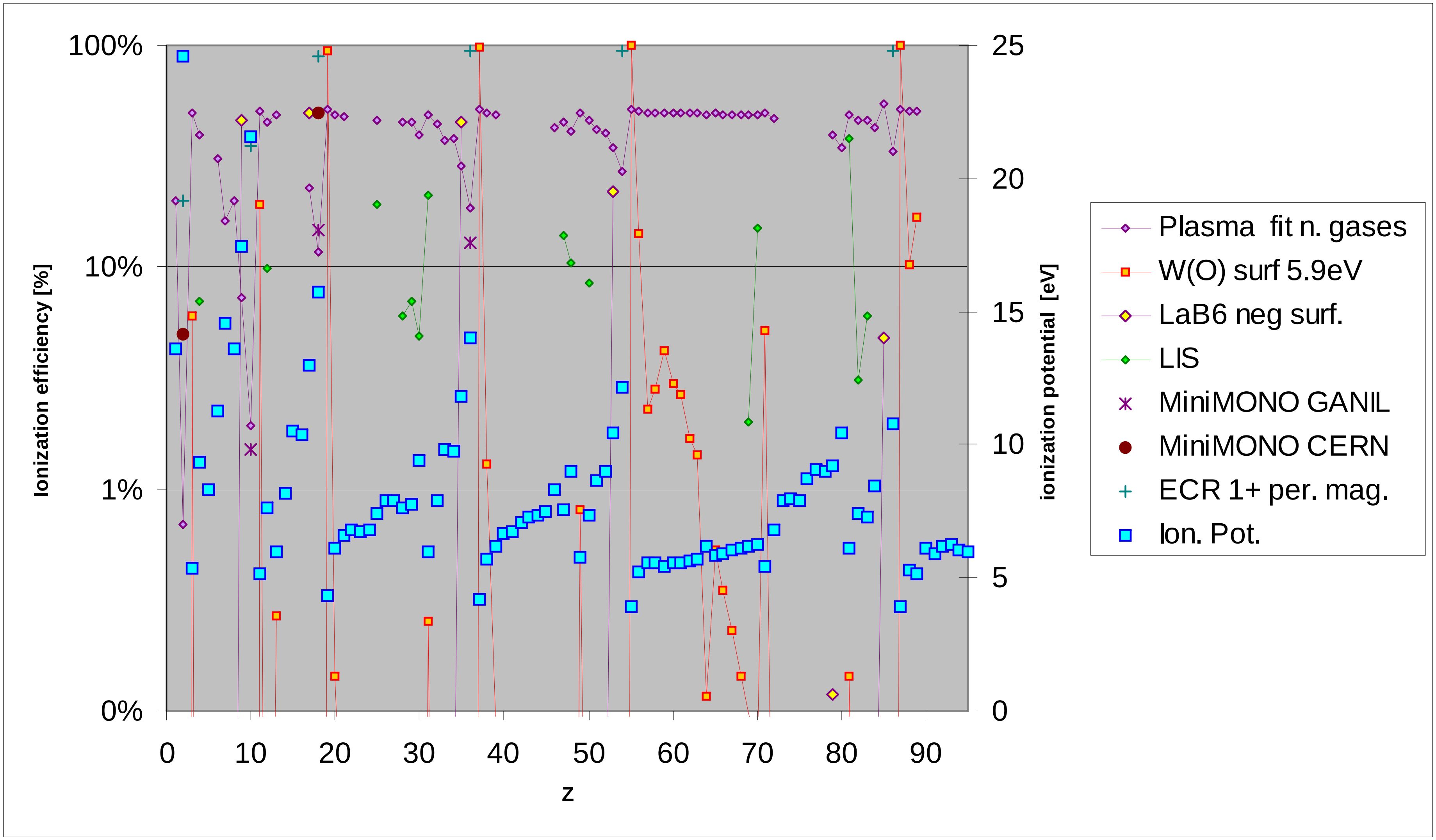
ISOLDE

RIB-Ion-sources efficiencies



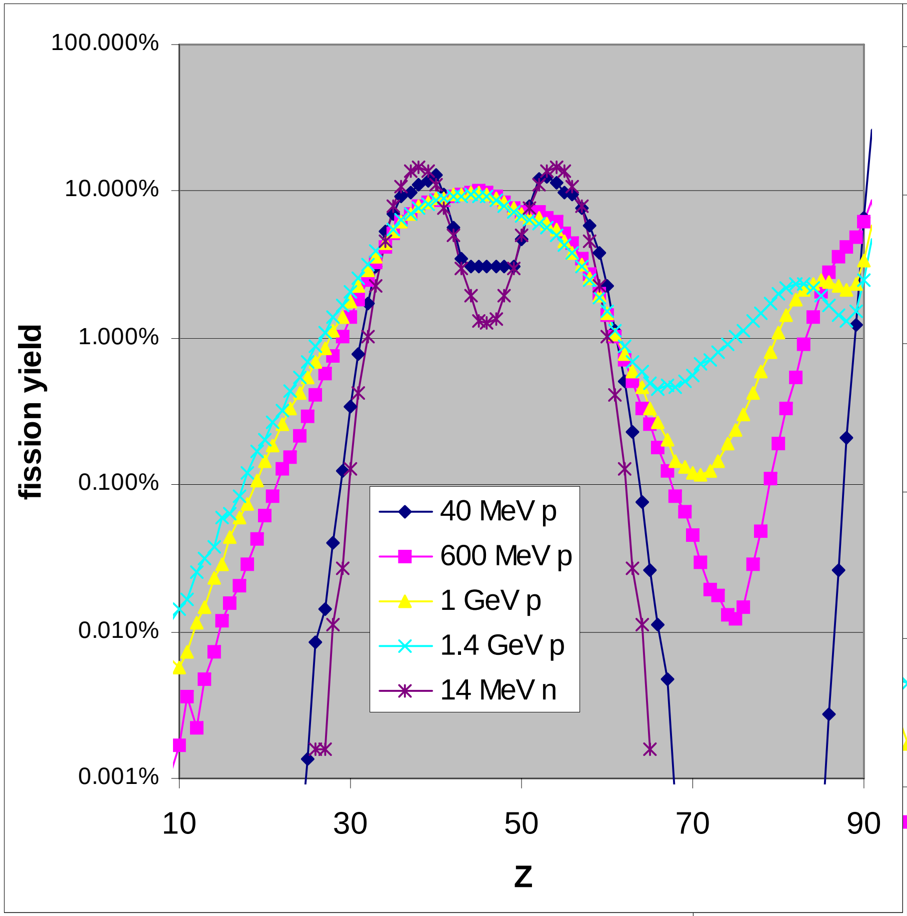


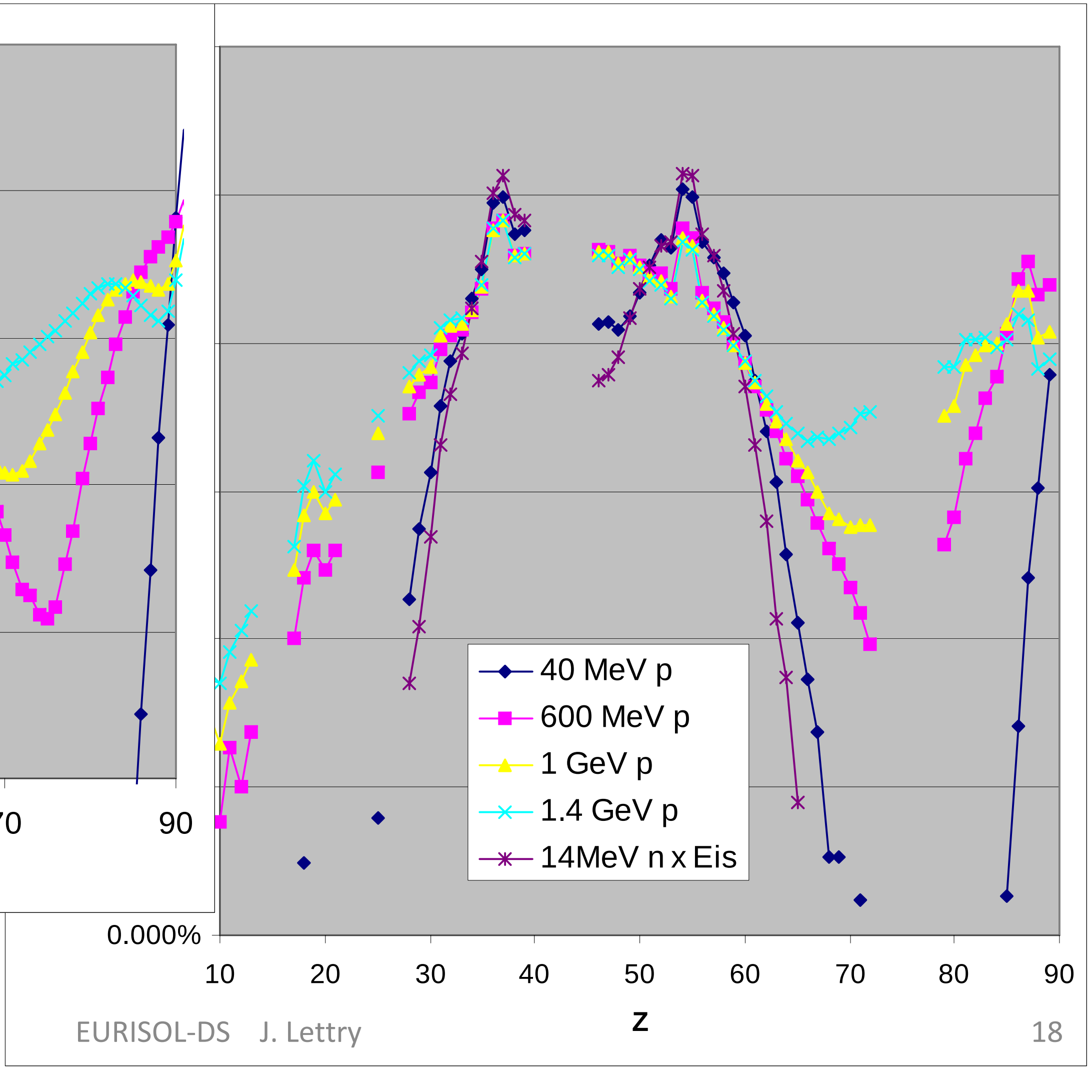
Ion source IP-extrapolated efficiencies of all elements released at ISOLDE SC and PS-booster



Fission yields :
Depleted Uranium target fissions induced via Proton & neutron

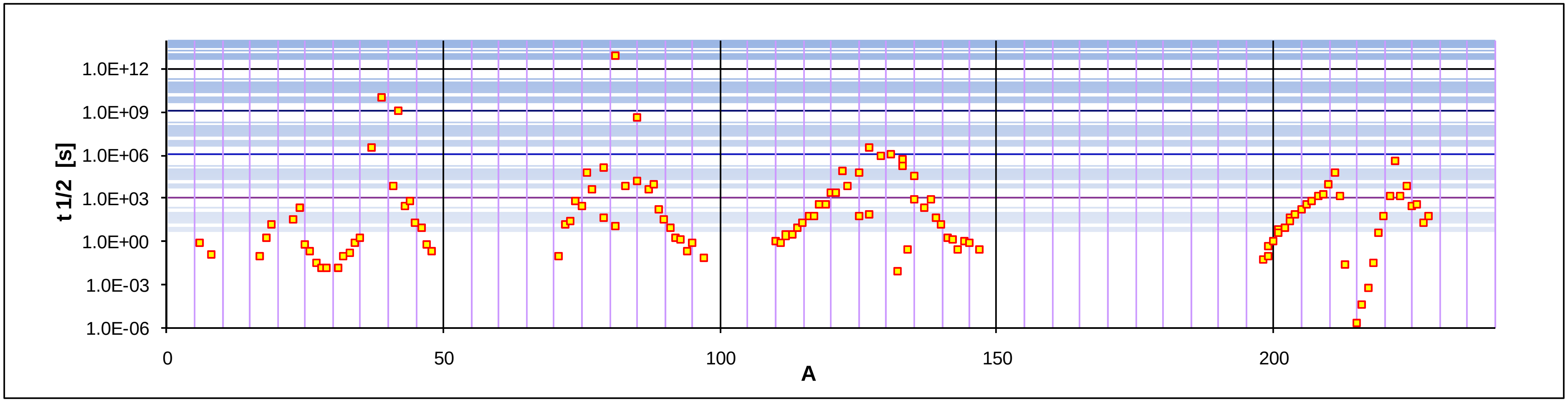
Estimation of the elements yields :
Prod. Rate × ionization eff. of best ion-source for elements produced at ISOLDE

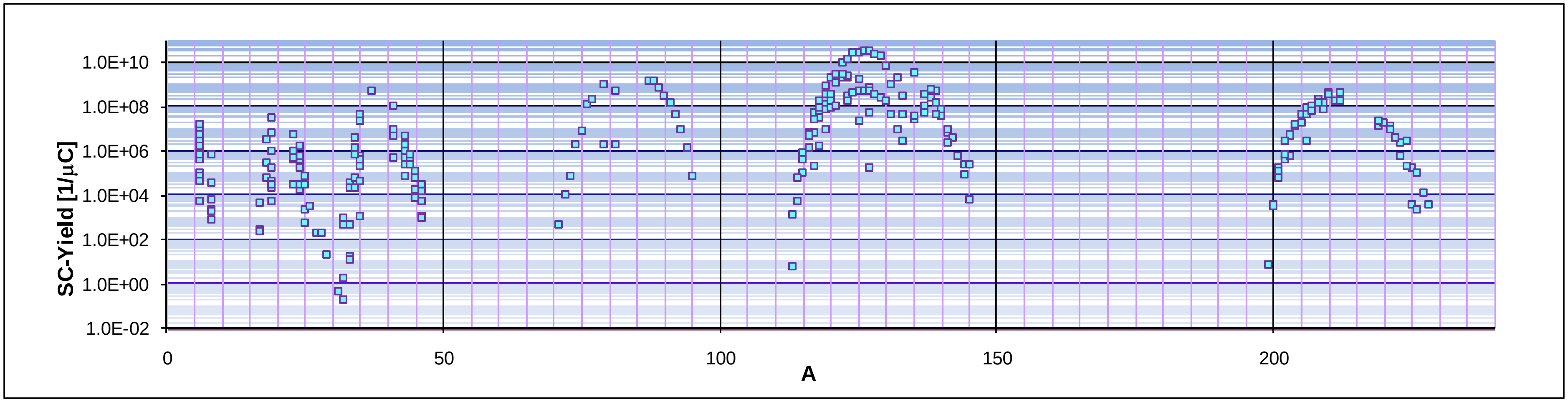




p-data: ABRABLA **GSI** (without IMF)

Noble gases: He, Ne, Ar, Kr, Xe, Rn
Extrapolation of ISOLDE-SC yields to MYRRHA-RIBs

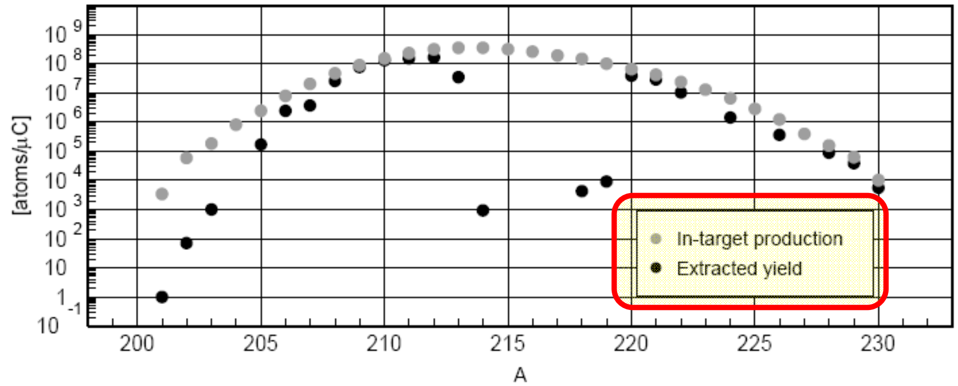




Assuming constant IS-Efficiencies and release fractions; and a 600 MeV proton driver of 100 µA:
MYRRHA-RIB rates [s-1] ≈ 100 × ISOLDE-SC Yields [1/µC]

On-Line Efficiencies:

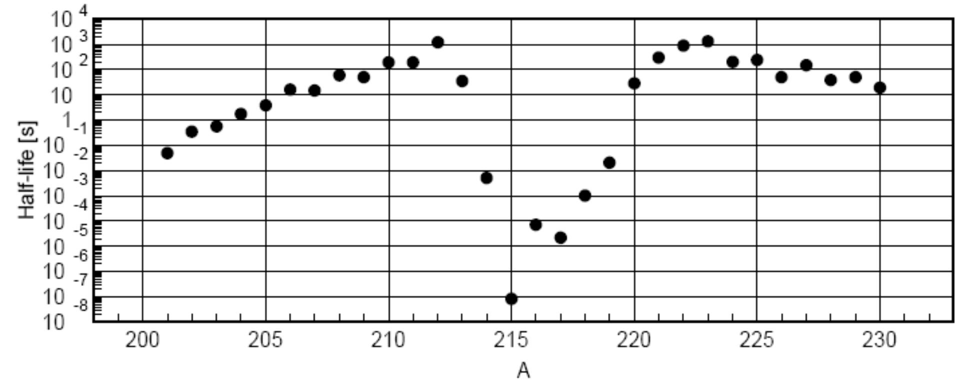
Fr RIBs from UC_x (13 g/cm²) at *ISOLDE-SC*



Systematic comparison of ISOLDE-SC yields with calculated in-target production rates

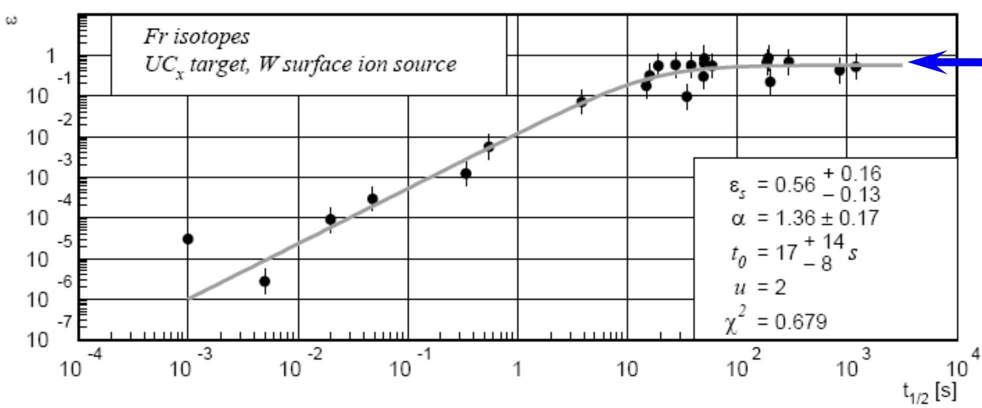
S. Lukić,[1] F. Gevaert, A. Kelić, M. V. Ricciardi, K.-H. Schmidt, O. Yordanov

GSI, Planckstr. 1, 64291 Darmstadt, Germany



Released Fraction × Ionization efficiency :

$\varepsilon(t_{½})$ = Yield / production rate



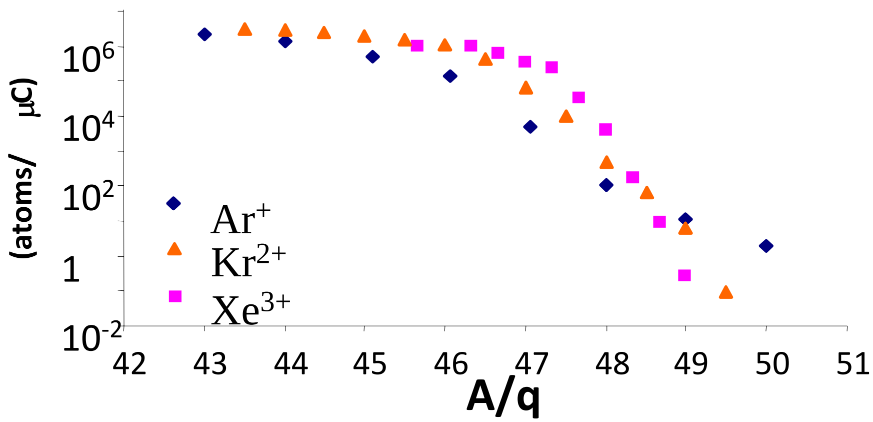
$\varepsilon_s = \varepsilon(t_{½} >> \text{release time}) \approx$ Ioniz. Eff.

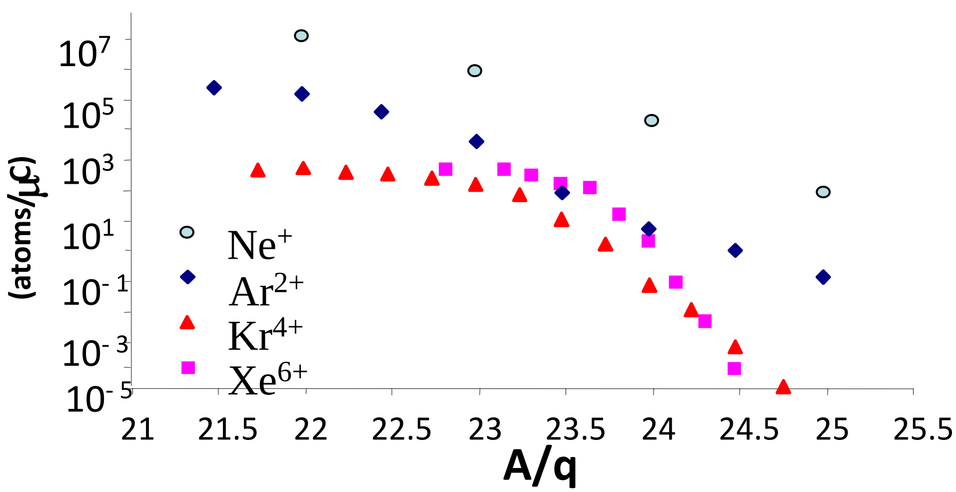
ISOLDE-SC-target materials for the production of Noble gases

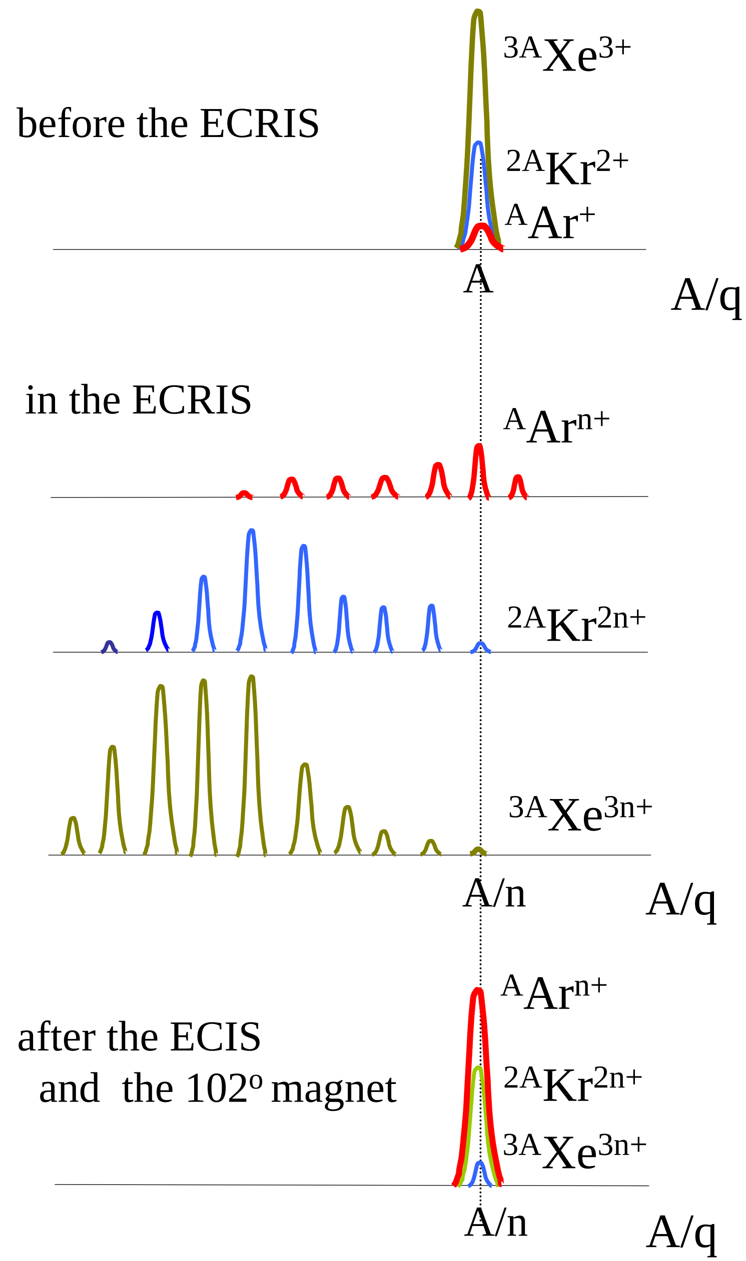
Noble Gases		IP	Ion-source efficiencies			GSI-fit	ISOLDE-SC Targets, X [g/cm2]	
		eV	FEBIAD	ECR		ε_s		
2	He	24.59	0.2%	20%				ThC, 55
10	Ne	21.56	0.7%	35%	1.5%	10.0%	MgO, 3	ThC, 55
18	Ar	15.76	6.6%	90%	14.7%	11.6%	CaO, 5.4	VC,38 ThC
36	Kr	14.00	12.8%	95%	13.0%	22.0%	Nb, 50	ThC, 55
54	Xe	12.13	23.9%	95%		*60%*	La, 124	ThC, 55
86	Rn	10.75	35.6%	95%				ThC, 55

Insulating material
Liquid target
10-30 kW

Enhancing Ar by charge breeding (ECR)

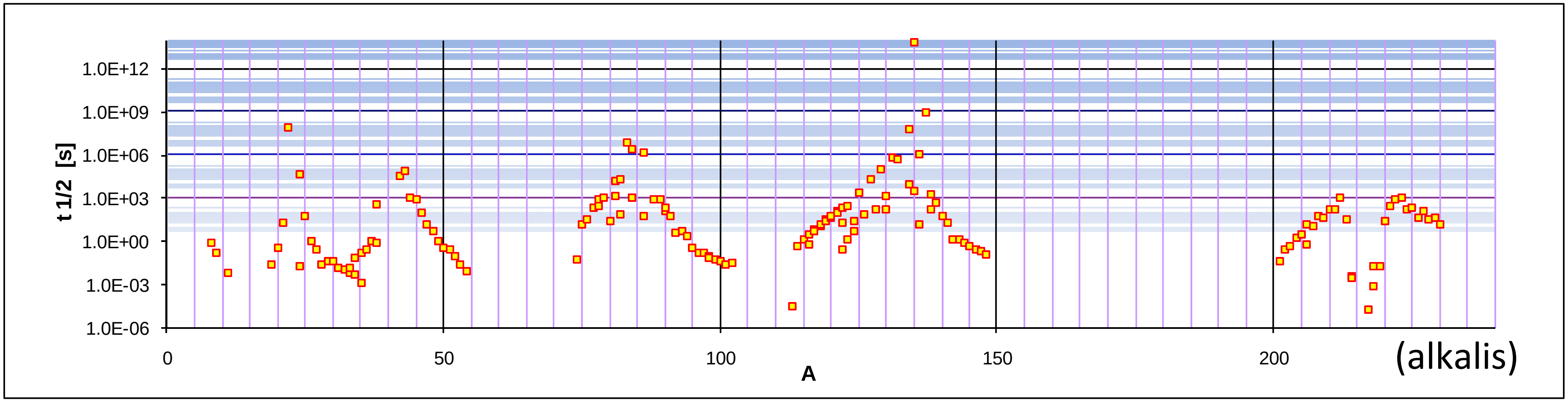


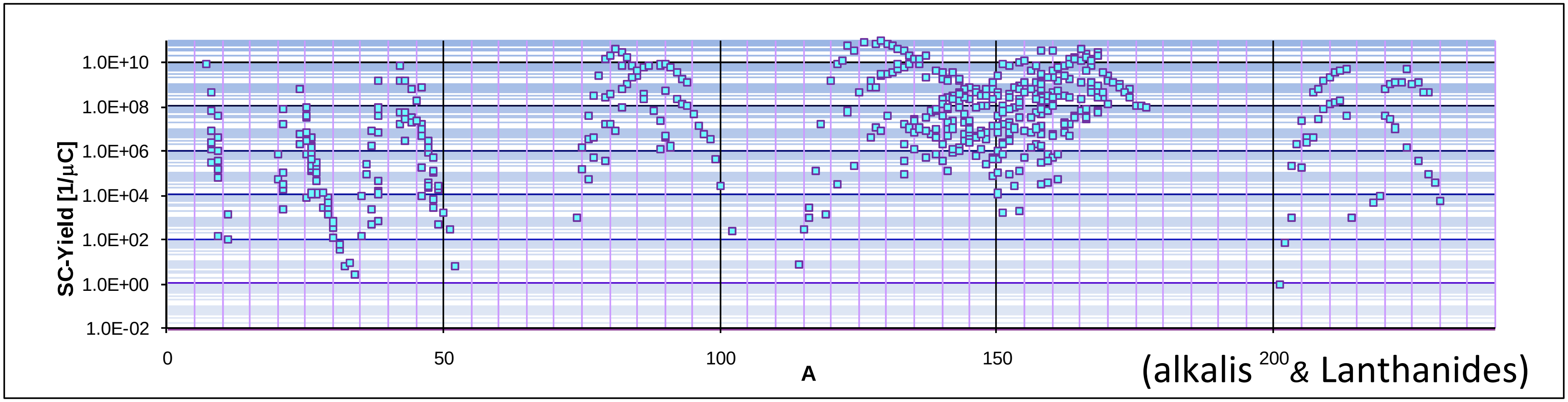




L. Weissman et al, PRC67(2003)054314

Alkalis Li, Na, K, Rb, Cs+ Lanthanides, Fr : Extrapolation of ISOLDE-SC yields to MYRRHA-RIBs





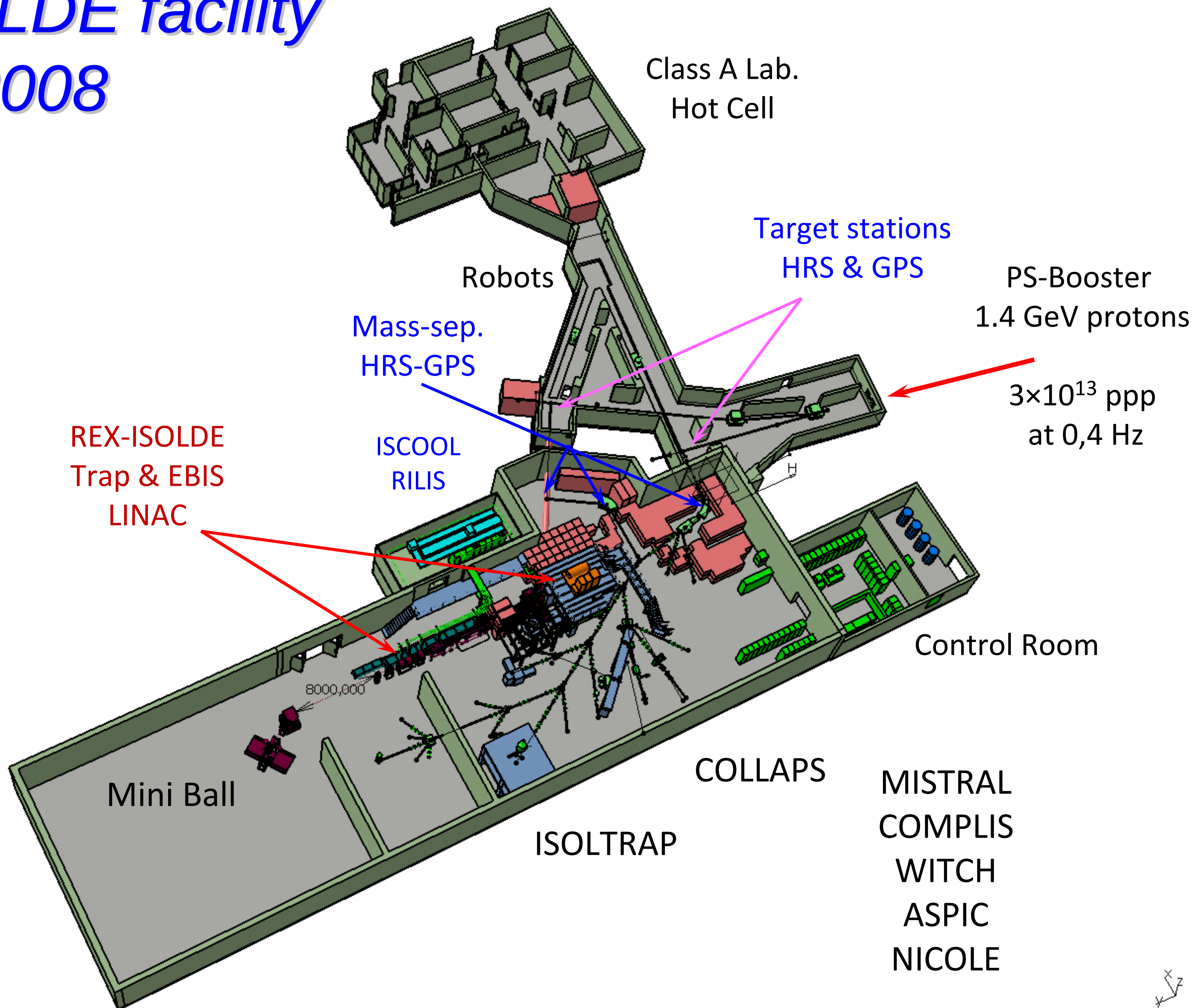
Assuming constant IS-Efficiencies and release fractions; and a 600 MeV proton driver of 100 μA: MYRRHA-RIB rates [s-1] ≈ 100 × ISOLDE-SC Yields [1/μC]

ISOLDE-SC-target materials for the production of Alkalis and Rare Earth

Alkalis & Lanthanides		IP	Hot-surf	GSI-fit	ISOLDE-SC Targets, X [g/cm2]	
		eV	W=5.3 eV	ε_s		
3	Li	5.39	23.7%		Ta, 133	UC, 13
11	Na	5.14	53.8%	26%	Ti, 40	UC, 13
19	K	4.34	98.8%	24%	Ta, 133	UC, 13
37	Rb	4.17	99.5%	41%	Ta, 133	UC, 13
55	Cs	3.89	99.9%	96%	Ta, 133	UC, 13
87	Fr	3.90	99.9%	56%		UC, 13
57	La	5.58	10.2%		Ta, 120	
58	Ce	5.54	12.4%		Ta, 120	
59	Pr	5.46	17.7%		Ta, 120	UC, 13
60	Nd	5.53	12.9%		Ta, 120	UC, 13
61	Pm	5.55	11.8%		Ta, 120	UC, 13
62	Sm	5.64	7.7%		GdLa, 29	Ta, 120
63	Eu	5.67	6.6%		GdLa, 29	Ta, 120
64	Gd	6.15	0.6%		Ta,120	
65	Tb	5.86	2.5%		Ta,120	
66	Dy	5.94	1.7%		Ta,120	
67	Ho	6.02	1.1%		Ta,120	
68	Er	6.11	0.7%		Ta,120	
69	Tm	6.18	0.5%		Ta,120	
70	Yb	6.25	0.3%		Ta-powder,120	
71	Lu	5.42	21.0%		Ta, 120	ThTa, 5.5

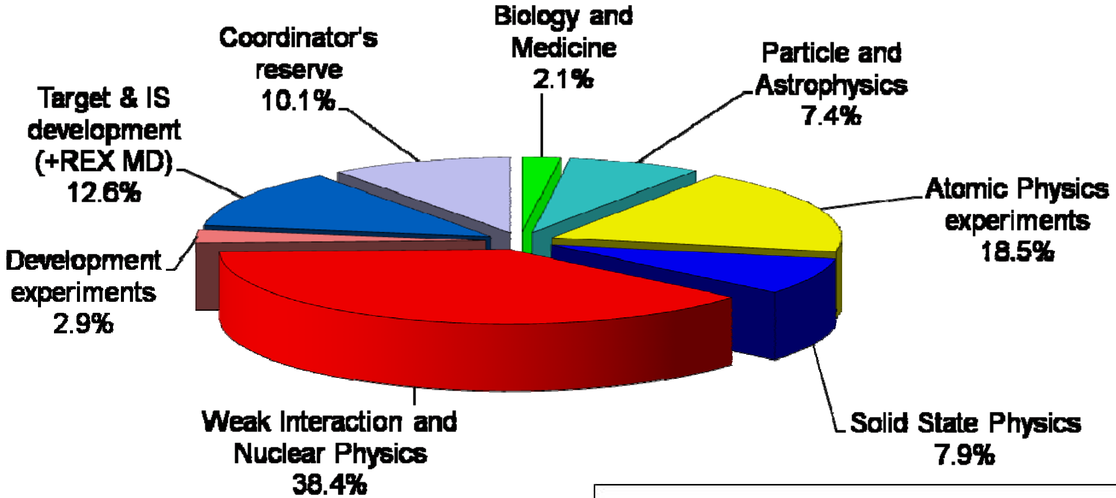
Low melting point
Liquid target
10-30 kW

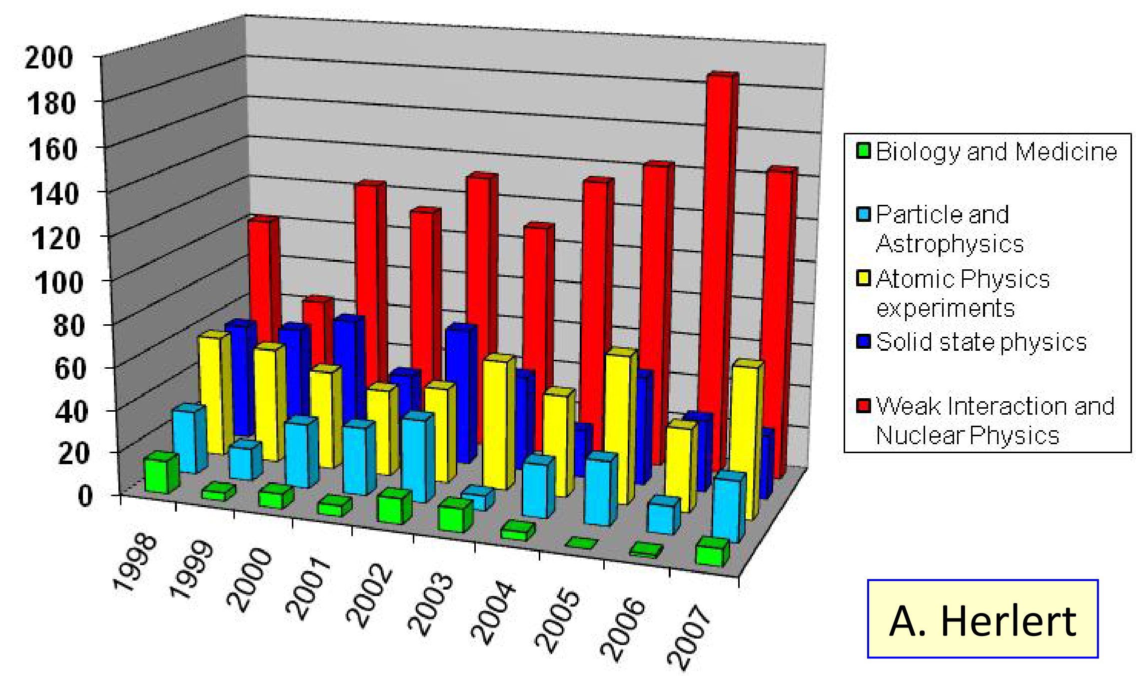
The ISOLDE facility 2008



Physics at ISOLDE

2007: 377 RIB-shifts (8h)
47% Resonant Laser ionization



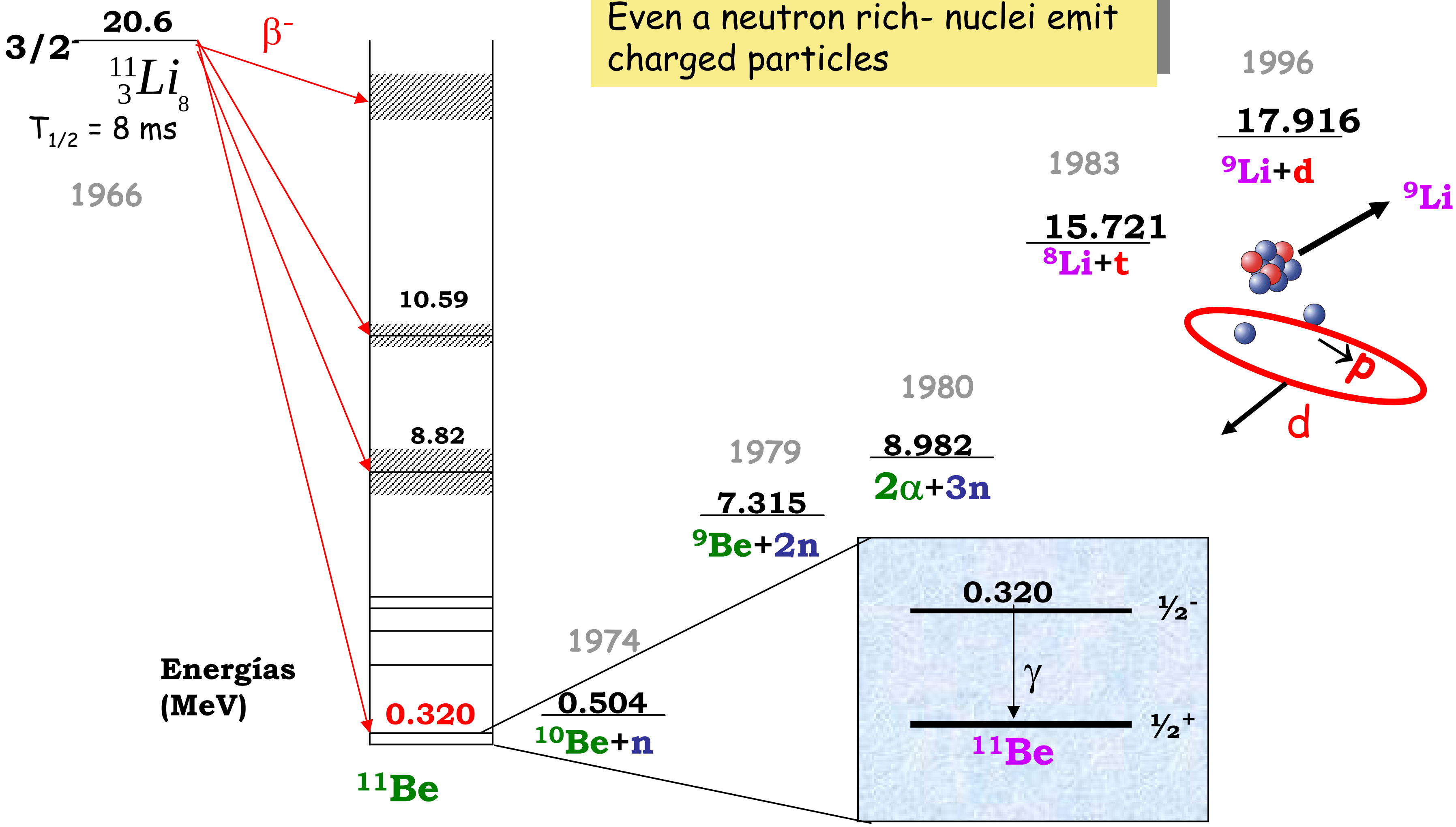


A. Herlert

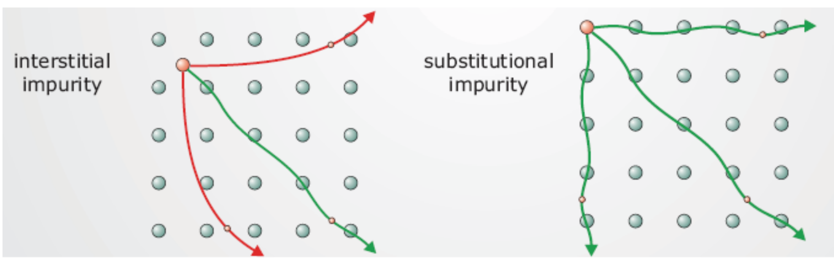
Nuclear physics:

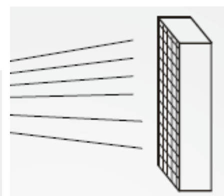
Beta decay of an exotic nuclei

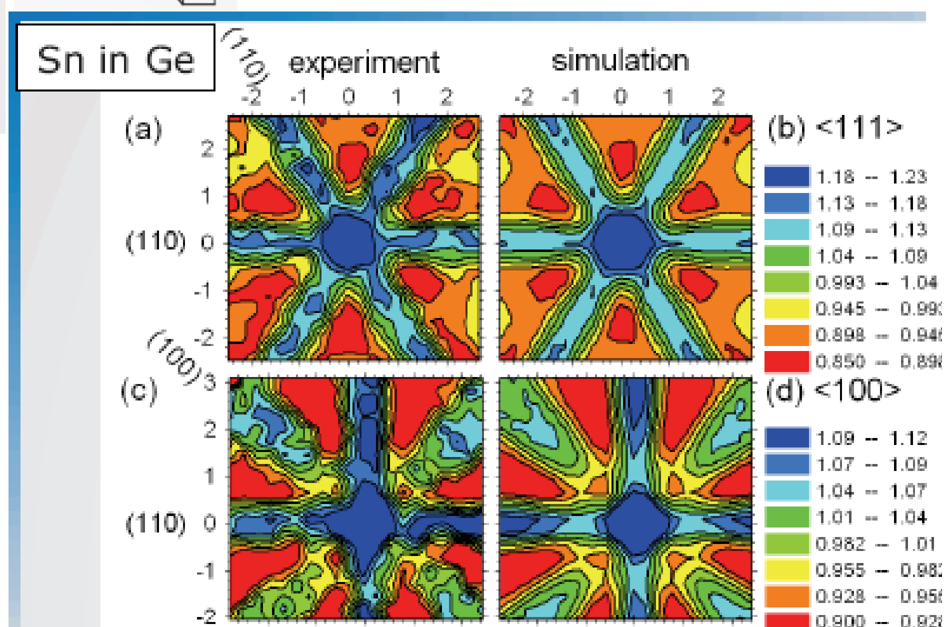
Even a neutron rich- nuclei emit charged particles



Solid state physics: Emission Channeling





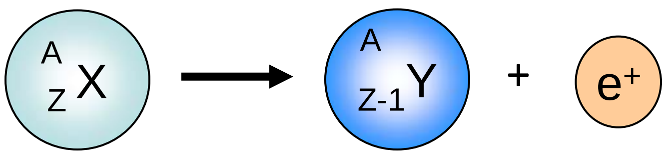


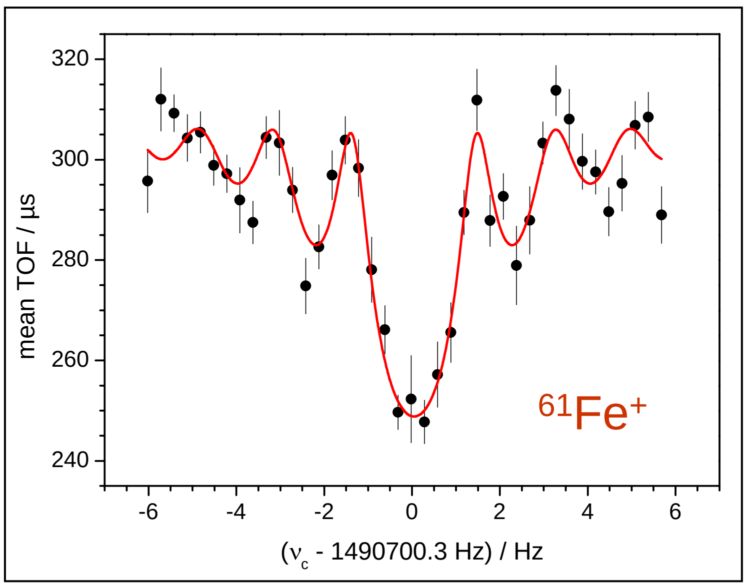
Study of annealing

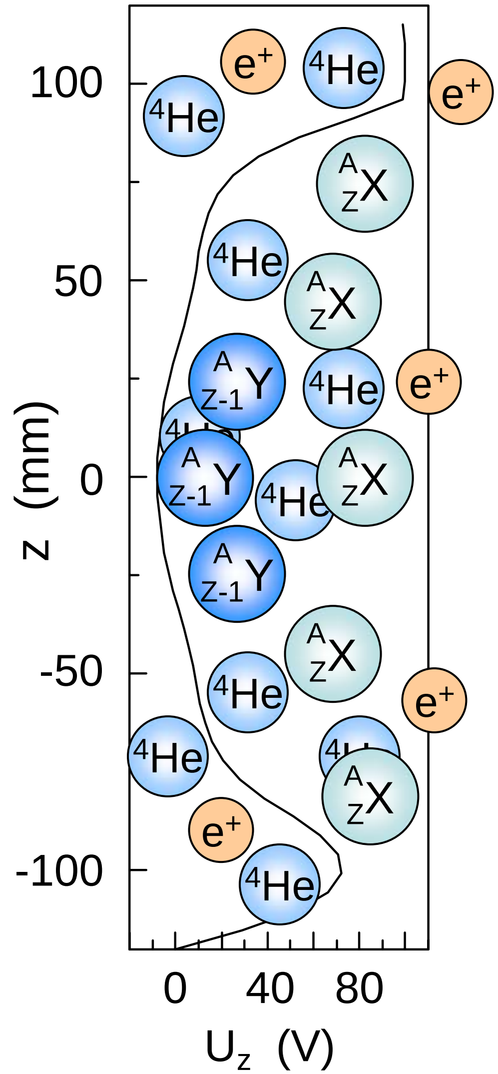
IS413: in-trap decay mass spectroscopy

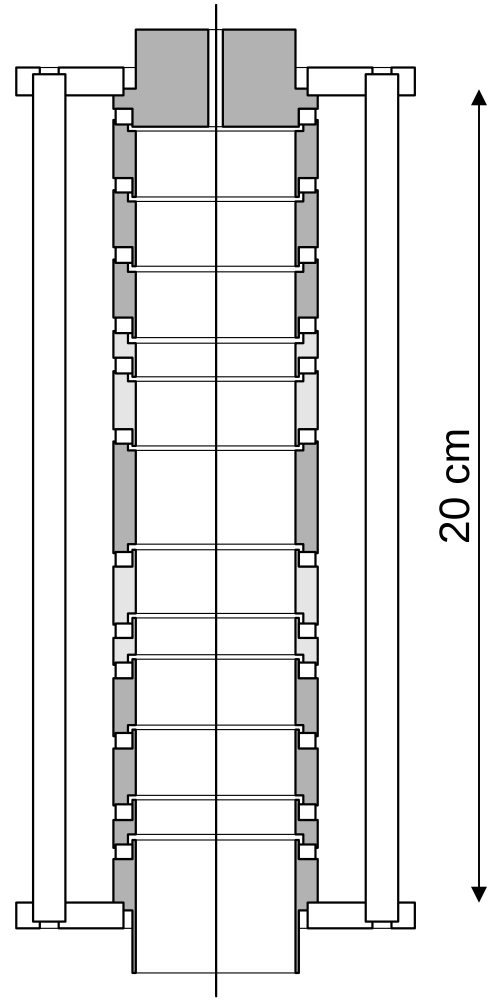
[A. Herlert et al.]

not produced
at ISOLDE









Preparation trap

Astro physics: *Rp-process above Z = 32*

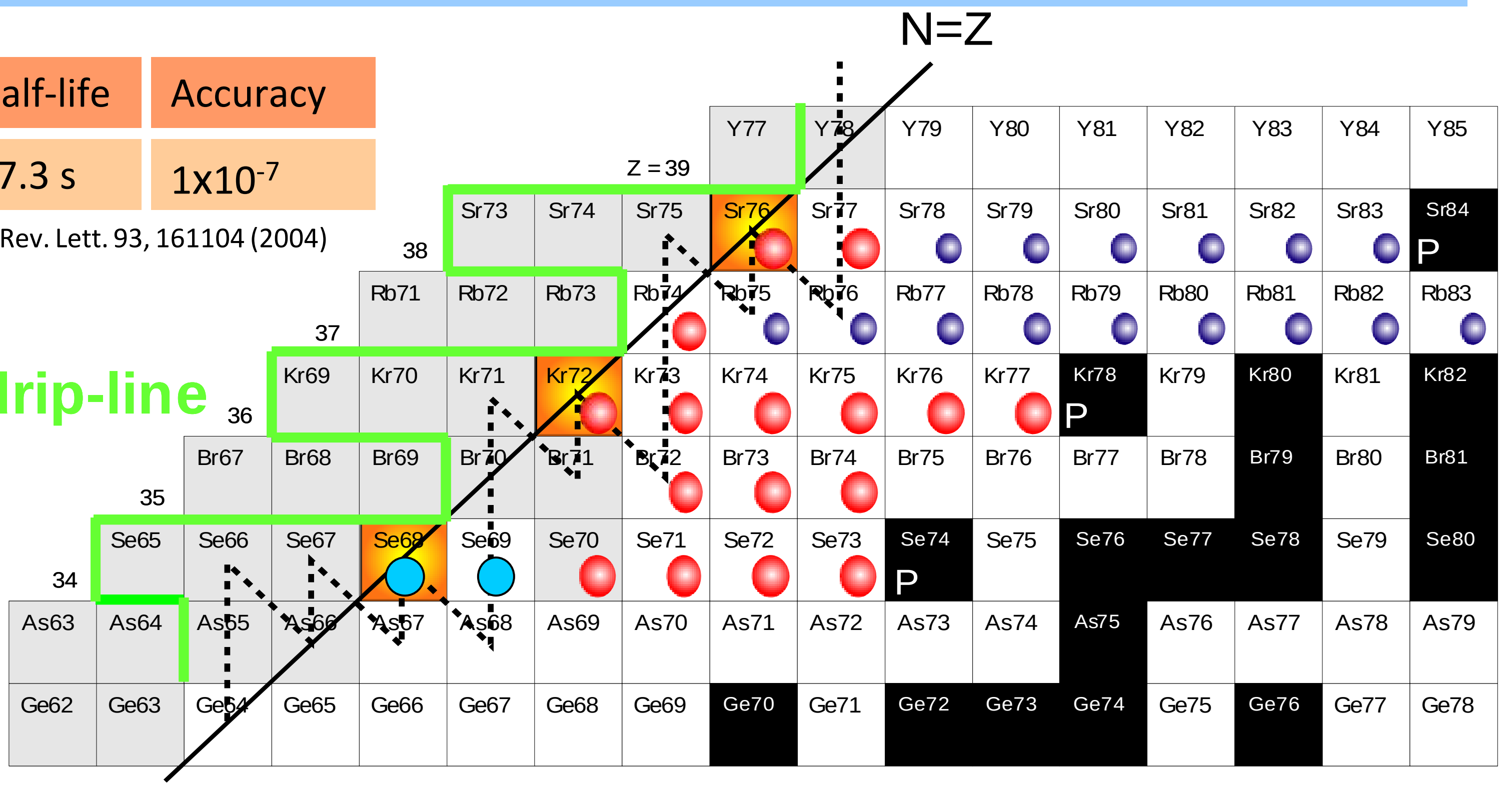
Masses are among the most critical nuclear parameters !

For trap, see presentation by K. Blaum

Nuclide	Half-life	Accuracy
^{72}Kr	17.3 s	$1x10^{-7}$

D. Rodríguez, Phys. Rev. Lett. 93, 161104 (2004)

Proton drip-line



----- possible rp - process main path (in type I x-ray bursts)

(H. Schatz et al. Phys. Rep. 294 (1998) 167)

possible waiting points

mass excess not yet measured *(AME95)*

ISOLTRAP measurements

2000 - 2002

before 2000

Canadian Penning Trap

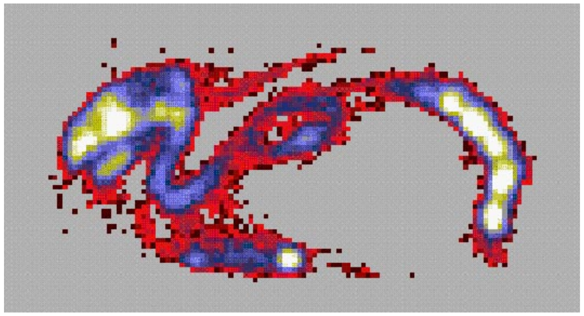
A. Jokinen et al.

Medical applications:

Alpha Therapy with ^{149}Tb

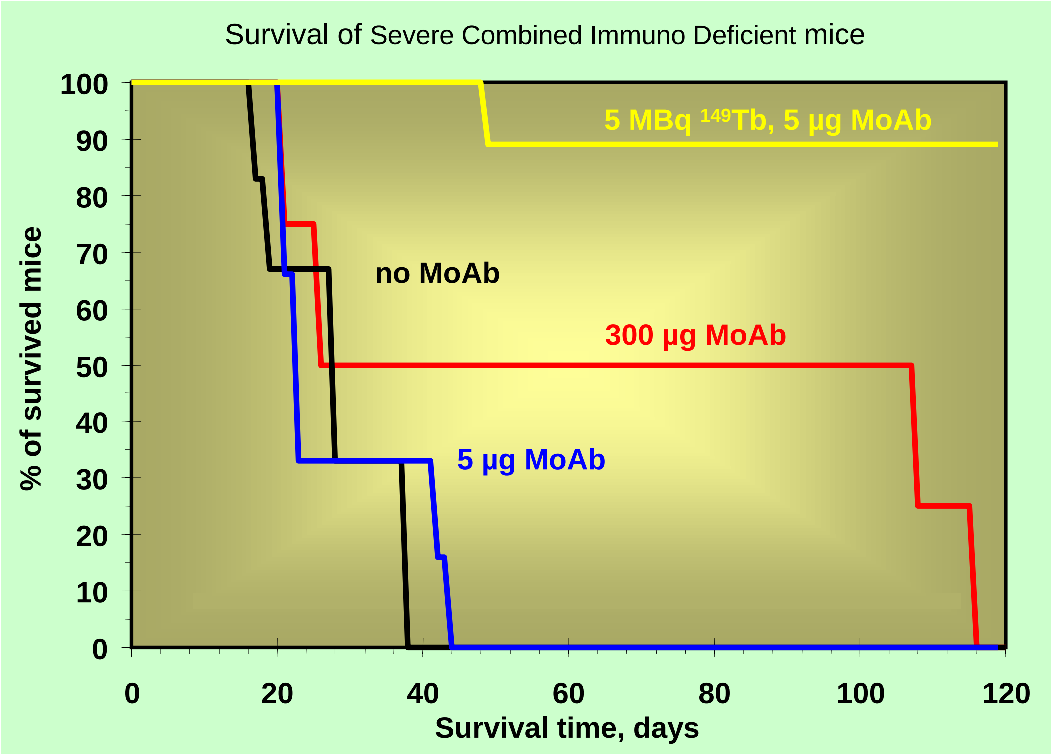
Radiolanthanides for PET

^{142}Sm EDTMP in vivo study



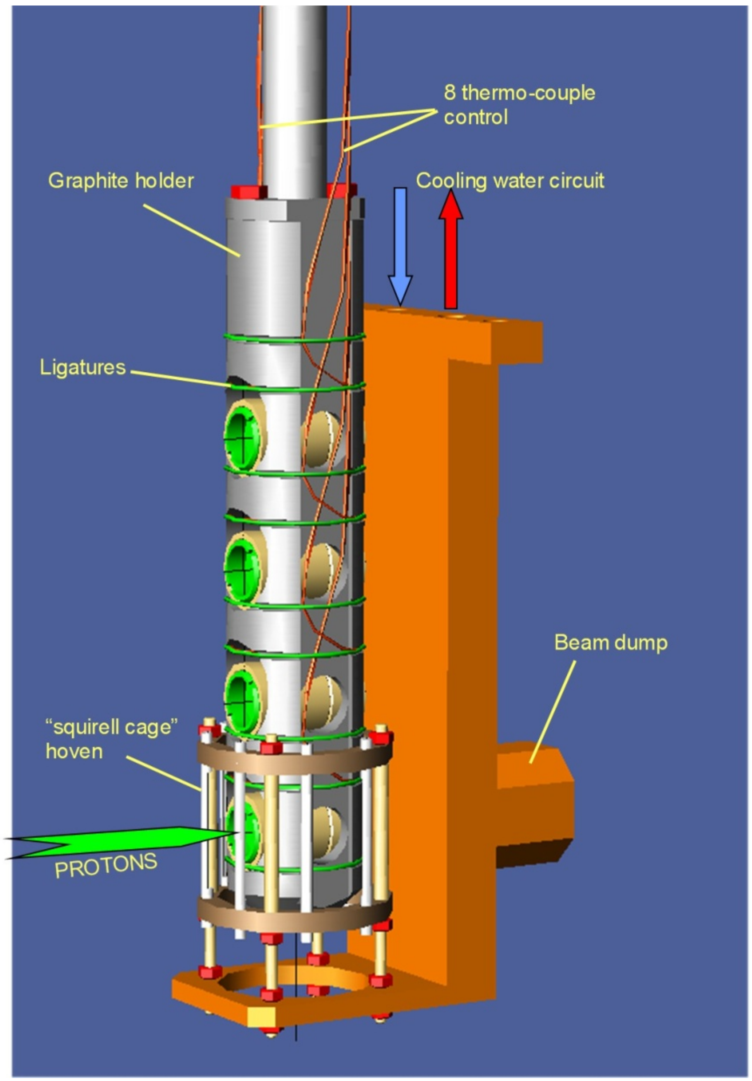
G. Beyer

10^5 Limphoma cells injection
After 2 days, treatment of the SCID mice



G.J.Beyer, M.Miederer, J.Comor et al., EJNM (2003)

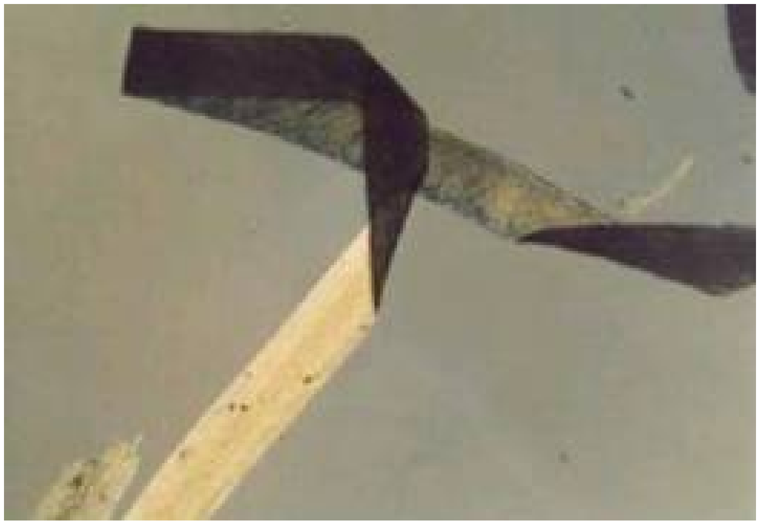
EURISOL-DS irradiation studies at PSI



- Development of multi-sample holder for the irradiation of prospective target materials for the EURISOL at the PSI-LISOR facility
- Testing mechanical and diffusion properties of various samples

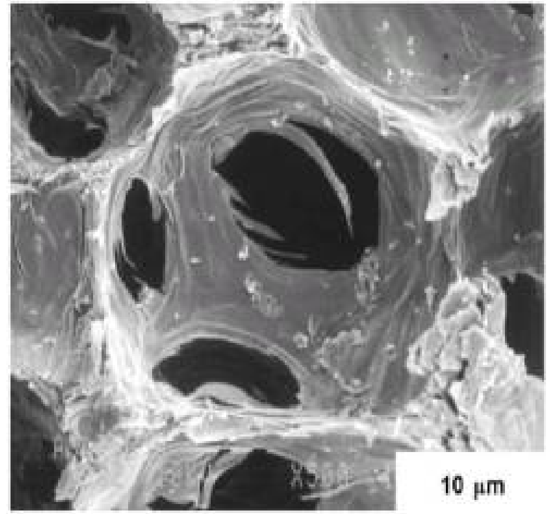
S. Marzari, R. Catherall, T. Stora, E. Bouquerel

Materials



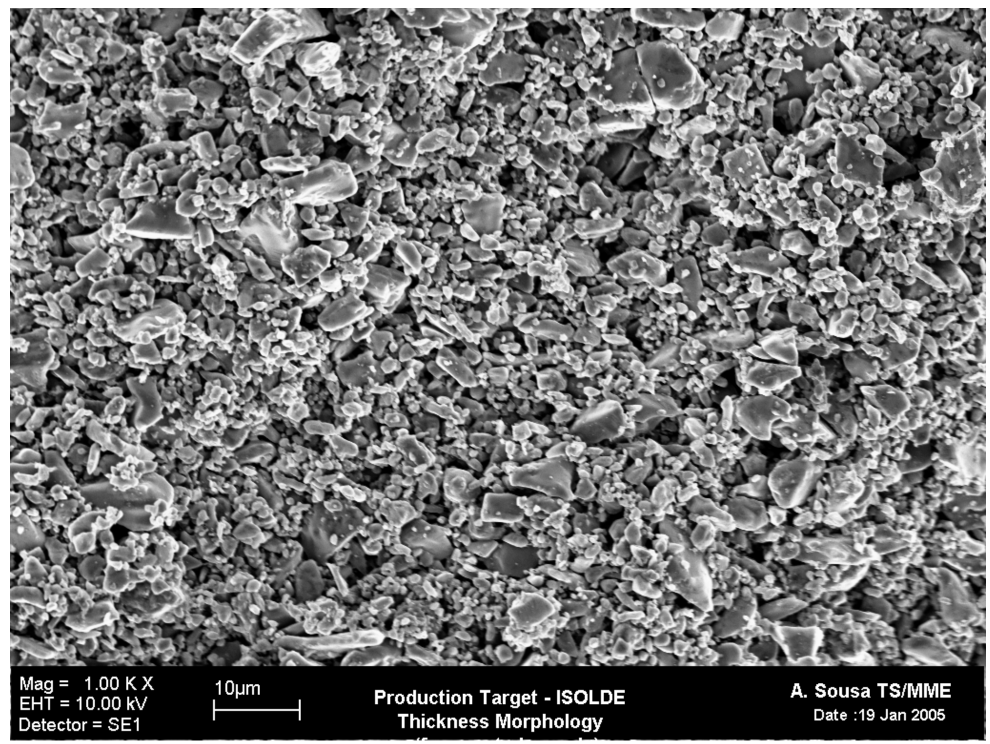
Fiber of carbon nanotubes
(Heat transfer properties)

Carbides C-fibers
Composites



Graphitic foam
ORNL

CERN-TS-MME



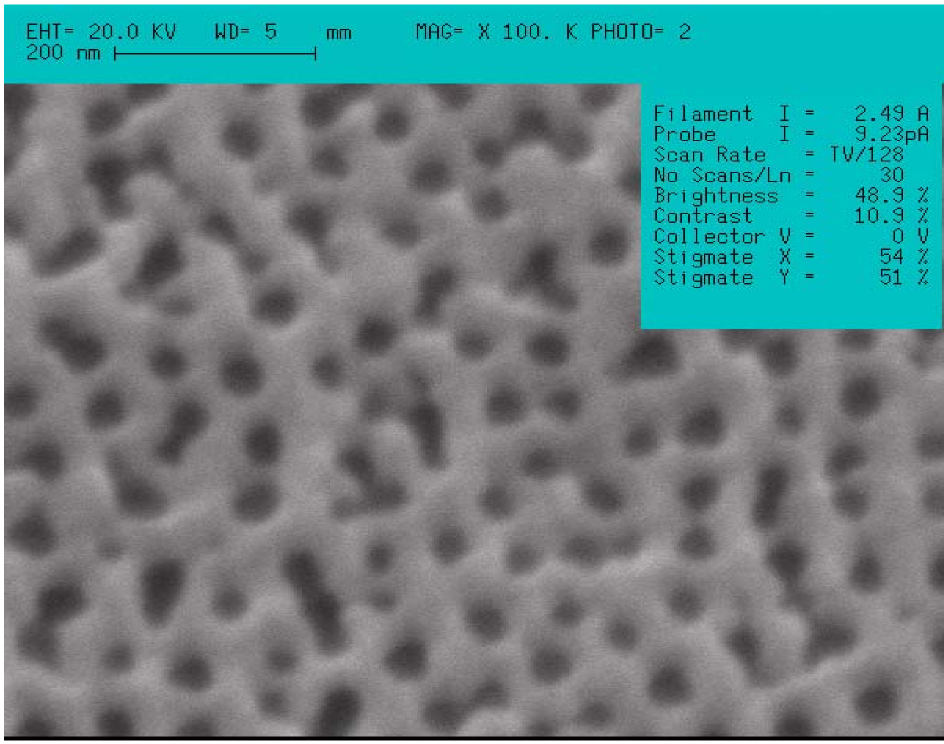
SiC-pressed powder

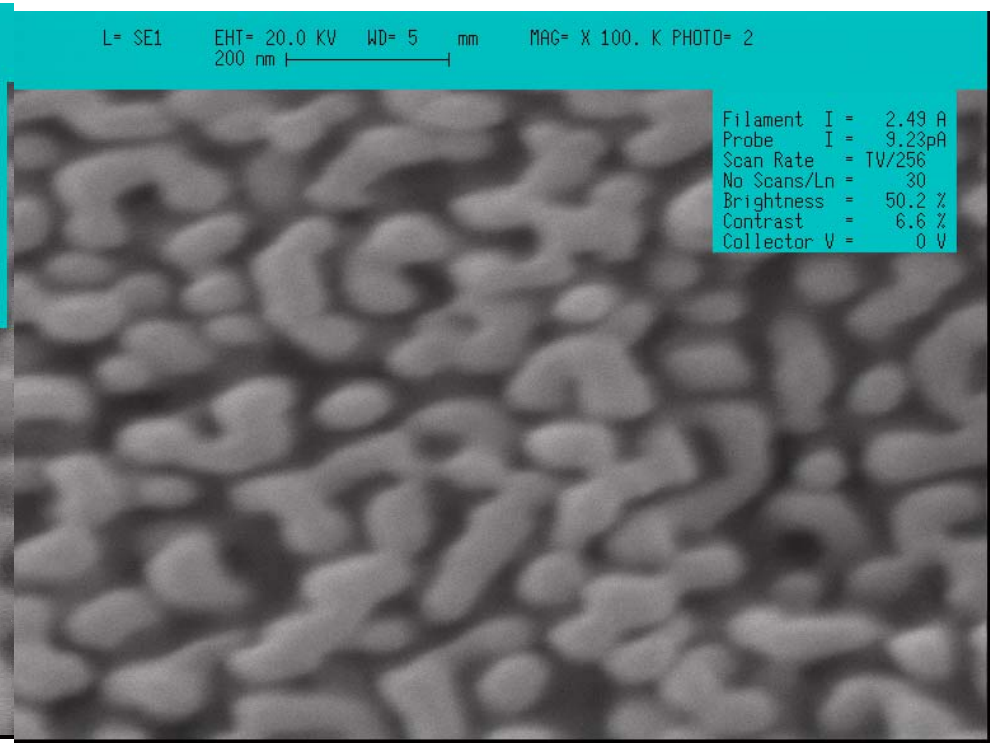
Super material design vs target life time

Nanostructure Al_2O_3

14h, 970 ºC

17h, 1250 ºC

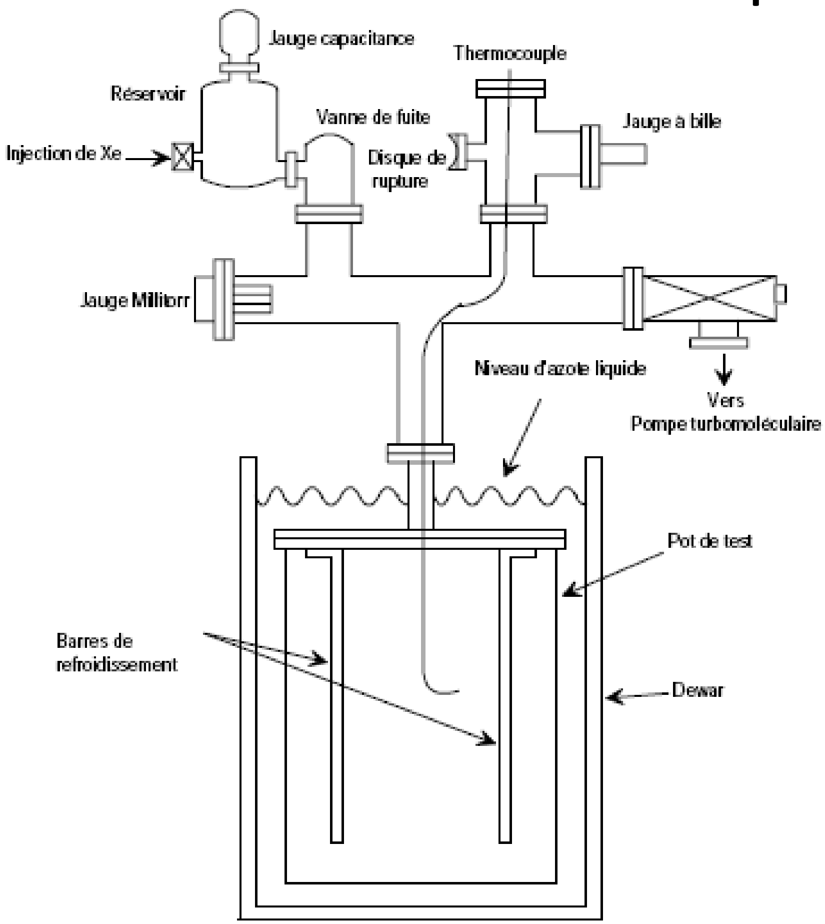


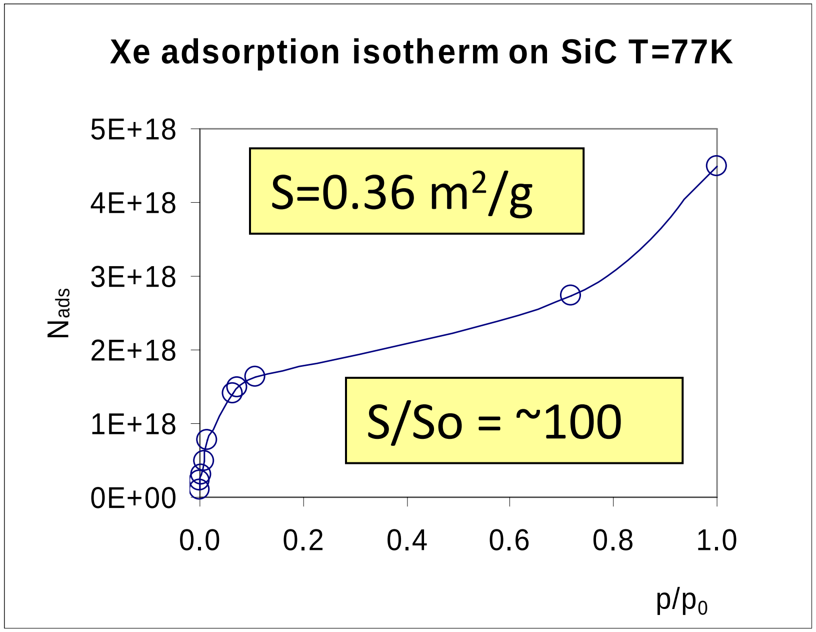


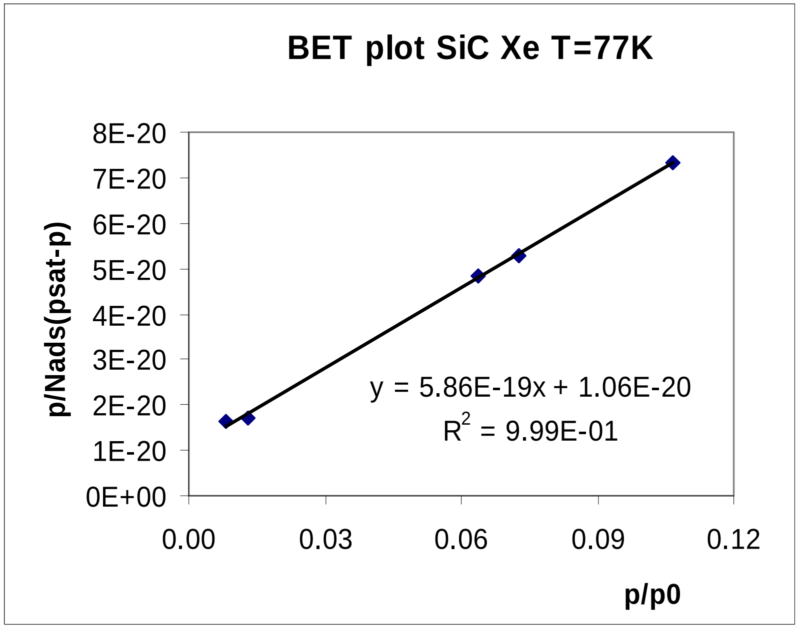
T. Stora

BET isotherm for specific surface ratio determination

i.e. SiC pills



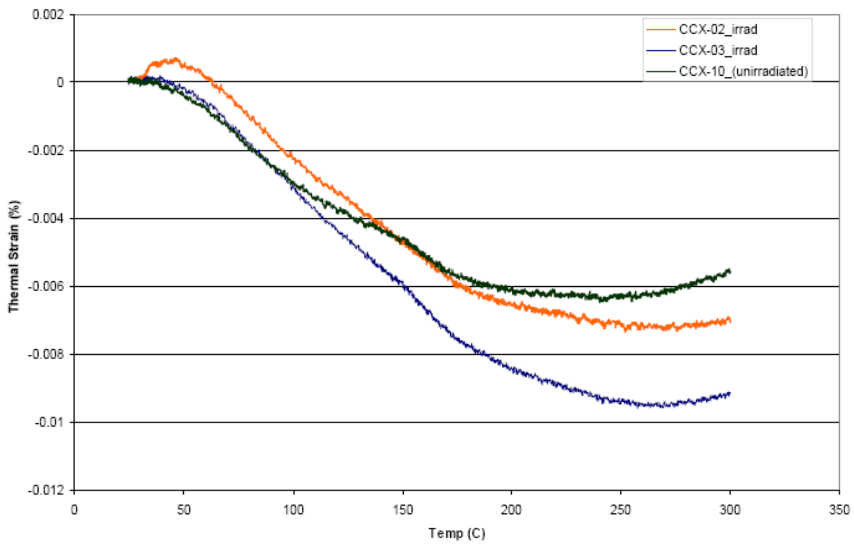




C-composite

Th-expansion

Ref: N.Simos et.at BNL



Th-conductivity

Ref: J.P. Bonal et C.H. Wu
Nucl. Mat. 277 (2000)

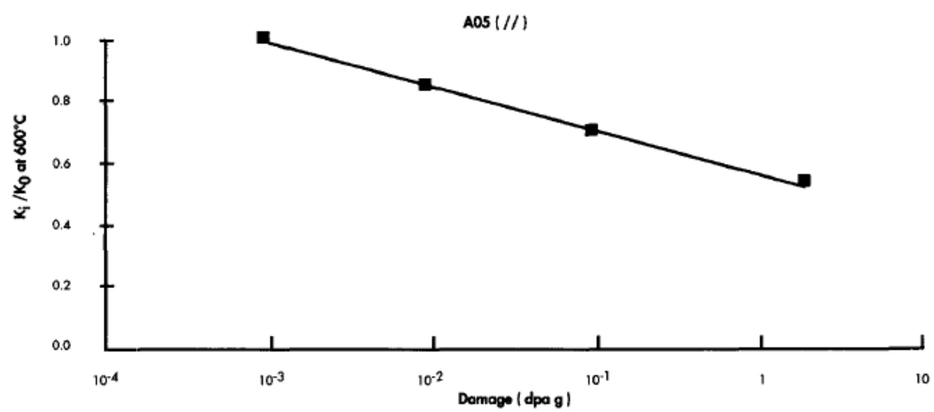


Fig. 4. Thermal conductivity A 05(||) normalized at 600°C as a function of neutron damage.

Do we need to measure these properties during irradiation at high temperature under realistic conditions ?

Summary - outlook

- Feasibility.
  - Production of Noble Gases via carbide, oxide or metallic targets equipped with cold transfer lines and ECRs
  - Production of Alkalis and rare earth via Metallic or Actinide targets and hot surface ion-sources
  - Actinide targets for fission fragment either with direct irradiation or via a n-spallation source.
  - Properties of target and ion-source materials under irradiation, Power dissipation and decay losses are studied within the EURISOL-DS targetry R&D program:
    - Towards 100 kW direct targets. T. Stora et.al.
    - Fissile targets driven by 4 MW spallation n-sources. Y. Kadi & L. Tecchio et.al
    - Safety aspects. D. Ridikas et.al
- Interest & needs
  - Broad research field are open world wide, among them noble gases and alkalis are the easiest to produce,
  - Applications requiring industrial reliability:
    - Medical applications of rare earths from Ta,W,Hg converters, free Fission products
      - U. Koester and Y. Kadi
  - All may require other elements, keep options open for other ion-sources and chemically selective systems as beam purity is often a requirement form users.